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STORAGE *of* APPLES

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STORAGE OF APPLES

STORAGE CONDITIONS

General Considerations

Apples while in the fresh state—whether attached to the tree or not are living material. This has a bearing on all problems associated with fresh apple storage. Its importance cannot be too strongly stressed in considering storage problems.

By virtue of the fact that apples are composed of living tissue their structure is made up of small units called cells. These cells must be kept intact and well supplied with food elements, principally sugars, if life is to be maintained. Just as an engine requires fuel—so do living living cells in the apple require sugars to function. The process by which living materials use sugars or other substances for energy is called respiration. This function usually results in the production of carbon dioxide and consumption of oxygen from the air. This explains the presence of considerable amounts of carbon dioxide often noted in large apple storages which have been kept closed.

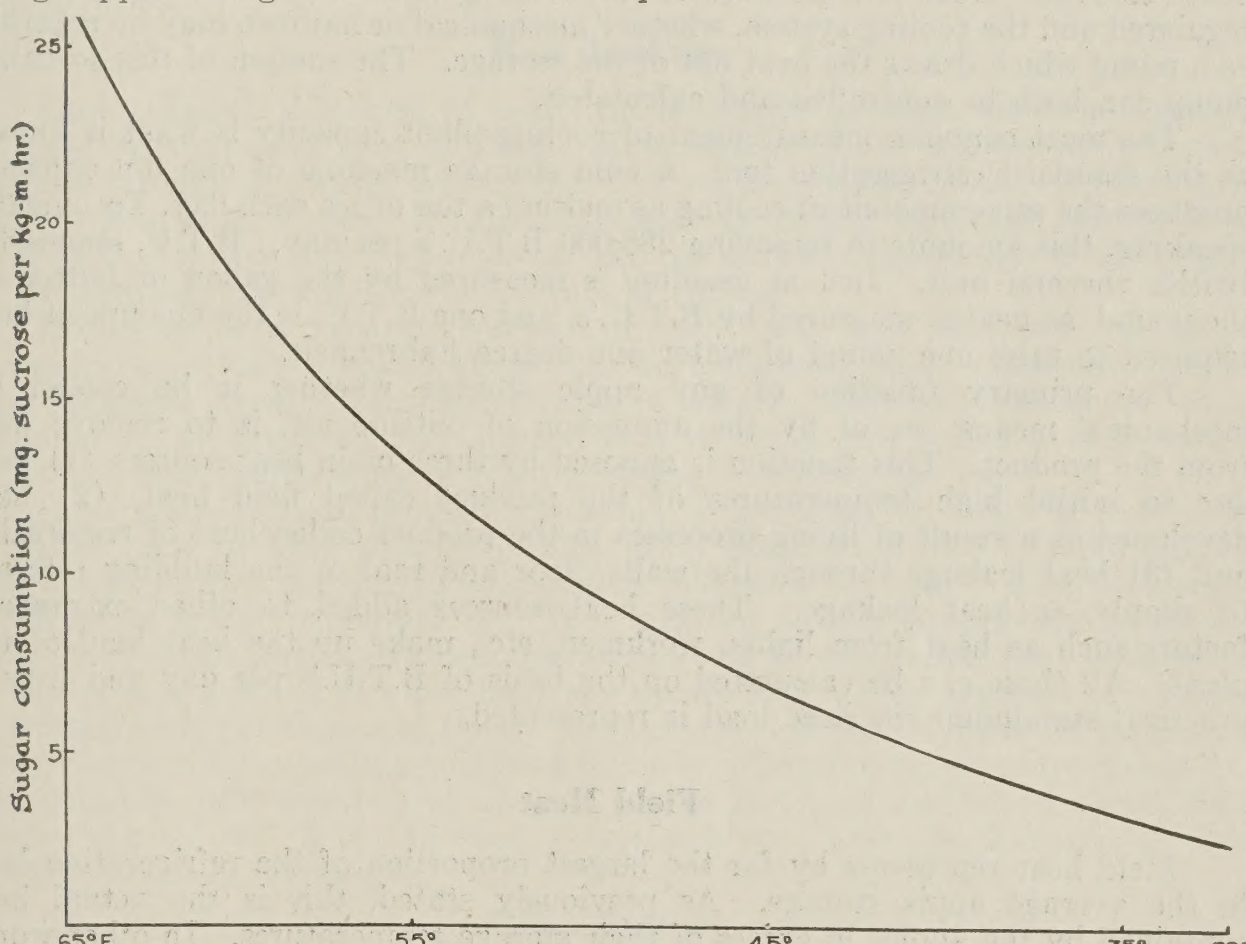

FIG. 1. Consumption of sugar (sucrose) in McIntosh apples at temperatures from 65°F. to 32°F. (Calculated on basis of CO_2 output)

Fig. 1 shows how temperature affects sugar consumption by McIntosh apples. It will be seen from this chart that sugar consumption is seven or eight times as great at 65°F. as at 32° to 35°F. This means that in general (there are exceptions) apples will last seven or eight times as long at 32° to 35°F. as they will at 65°F. Furthermore, this demonstrates the importance of getting apples into storage as quickly as possible.

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Another important point is that it is the apple temperature that governs the length of storage life and not the air temperature of the storage. For this reason the apple temperature should be reduced to the temperature of the storage as quickly as possible. A large quantity of apples may be improperly stowed in a large storage room. The air temperature as indicated by a thermometer in the room may be reduced to the desired point within twenty-four hours. If a thermometer were placed in apples at the centre of the stack, however, it might be found that the apples did not reach storage temperature for a matter of weeks. It is obvious then that such apples will be consuming their reserve food at a much more rapid rate than is necessary, resulting in a much shortened storage life. Thus the importance of getting apples down to the proper storage temperature as quickly as possible is evident. It follows that holding the fruit at this temperature is equally important.

Heat Calculations in Storage

It is natural to think of cold storage equipment in terms of cooling capacity. This frequently leads to misconception and error. In order to adequately understand refrigeration problems the process must be looked upon as one of heat removal. Heat is a positive form of energy which can be measured and regulated and the cooling system, whether mechanical or natural, may be regarded as a pump which draws the heat out of the storage. The suction of this so-called pump can both be controlled and calculated.

The most common measurement of cooling-plant capacity is what is known as the standard refrigeration ton. A cold storage machine of one ton capacity produces the same amount of cooling as melting a ton of ice each day. Technically speaking, this amounts to removing 288,000 B.T.U.'s per day. B.T.U. stands for British thermal unit. Just as gasoline is measured by the gallon or butter by the pound, so heat is measured by B.T.U.'s, and one B.T.U. is the amount of heat required to raise one pound of water one degree Fahrenheit.

The primary function of any apple storage whether it be cooled by mechanical means, ice or by the admission of outside air, is to remove heat from the product. This function is opposed by three main heat sources (1) heat due to initial high temperatures of the product called field heat, (2) heat developed as a result of living processes in the product called heat of respiration and (3) heat leakage through the walls, floor and roof of the building referred to simply as heat leakage. These heat sources added to other extraneous factors such as heat from lights, workmen, etc., make up the heat load of the plant. All these can be calculated on the basis of B.T.U.'s per day and from a practical standpoint the heat load is represented.

Field Heat

Field heat represents by far the largest proportion of the refrigeration load in the average apple storage. As previously stated, this is the actual heat contained by the apples in excess of their storage temperatures. In other words it is the amount of heat that must be withdrawn from the fruit to reduce it to storage conditions.

In order to compute this heat load the maximum daily input of apples must be known. It is also important to know the probable maximum temperatures at which these will be harvested. Assuming that apple tissue is largely water, it requires one B.T.U. to reduce the temperature of one pound of apples one degree Fahrenheit.

For example, it may be estimated that the maximum daily input is 1,000 bushels (allowing 45 pounds per bushel) at a temperature of 80°F. These are to be cooled to 32° F. This represents 45,000 pounds which are to be cooled 48°

(80–32). Thus the maximum daily field heat load is 2,160,000 B.T.U.'s (45,000 $\times$ 48). On the basis of 288,000 B.T.U.'s per ton this represents a heat load of about $7\frac{1}{2}$ tons of refrigeration. Thus the method for determining field heat load in tons of refrigeration is as follows:

weight of apples pounds $\times$ difference between harvest and storage temperature divided by 288,000.

Heat of Respiration

This heat is continuous throughout the storage life although it is decreased with temperature. A ton of apples at 85°F. generates about 11,000 B.T.U.'s, at 40°F. about 1400 B.T.U.'s and at 32°F. about 700 B.T.U.'s daily. Thus under maximum respiratory conditions this only amounts to ·04 tons of refrigeration per ton of apples. Respiration heat under storage conditions necessitates the allowance of about ·0024 tons daily.

This might appear insignificant at a casual glance but consider what it involves for a small storage of 25,000 bushels. In weight this represents about 562 tons which will require approximately $1\frac{1}{2}$ tons of refrigeration. Even this is small compared with the field heat load but it is large enough to warrant consideration.

Heat Leakage

Unfortunately this form of heat load is usually greatest when the demand for field heat removal is at its peak. Heat leakage is the amount of heat that filtrates through the walls, ceiling and floor of the storage room. Insulation is used to help control this. In an uninsulated or poorly insulated storage heat leakage is excessive and may over-tax the refrigeration equipment to the extent of jeopardizing the welfare of the fruit in storage.

Insulation is a separate subject of itself and only the bare essentials necessary to calculate heat leakage will be mentioned here. Corkboard is the most common form of insulation and is almost universally accepted as a standard. The usual amount applied is 4 inches in the walls, 3 to 4 inches under the floor and 6 inches in exposed ceiling (i.e. under the roof).

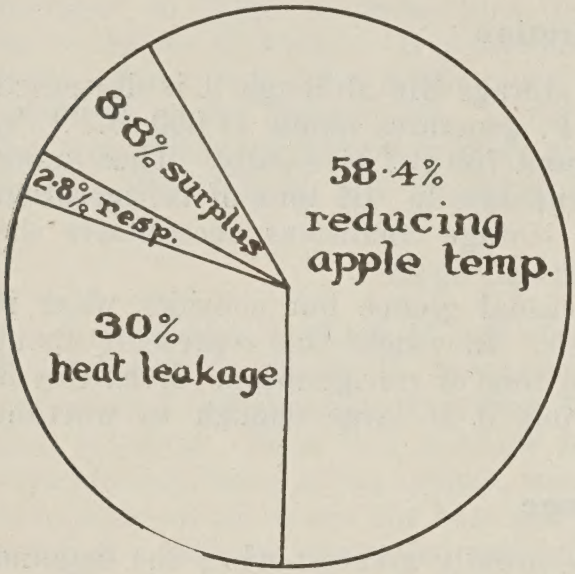
Infiltration of heat through insulation is measured by what is known as K value (rate of heat transfer). The usual standard is B.T.U.'s per square foot one inch thick per degree temperature difference per hour. With corkboard the K value is approximately ·3. Thus with an outside temperature of 80°F., 4 inches of corkboard in a storage operating at 32°F. will permit heat infiltration at the rate of 3·6 B.T.U.'s per hour per square foot. This amounts to ·3 tons of refrigeration per thousand square feet per day. If the thickness of insulation is increased or decreased the heat infiltration is reduced or raised proportionately. For example, 1000 square feet of wall with 8 inches of corkboard would only require one-half of ·3 or ·15 tons of refrigeration. Likewise 2 inches of cork would necessitate ·6 tons.

Other Factors

Lights, door openings, electric motors, etc., all constitute sources of heat. In exceptional instances these have to be given special consideration. If, however, field heat, heat leakage and heat of respiration are amply considered the surplus would take care of these factors.

From the preceding considerations it is obvious that by far the largest heat load is in the fall of the year when the storage is being filled with apples. Once these are cooled down and outside temperatures become cooler the heat load very nearly vanishes. This is shown in Fig. 2. It will be noted that heat leakage in A and B are the same. In other words the outside temperature conditions are constant in both. As the temperature drops the surplus of 68·6

per cent as shown in B will continue to increase. When outside temperatures are at 32°F. (storage temperature) or lower heat leakage will be eliminated. Under this last condition the total operating load will be less than 2 per cent of the maximum. This theoretical condition may not be approached but it is usually assumed that the amount of refrigeration required at loading is ten times the amount needed during the winter.



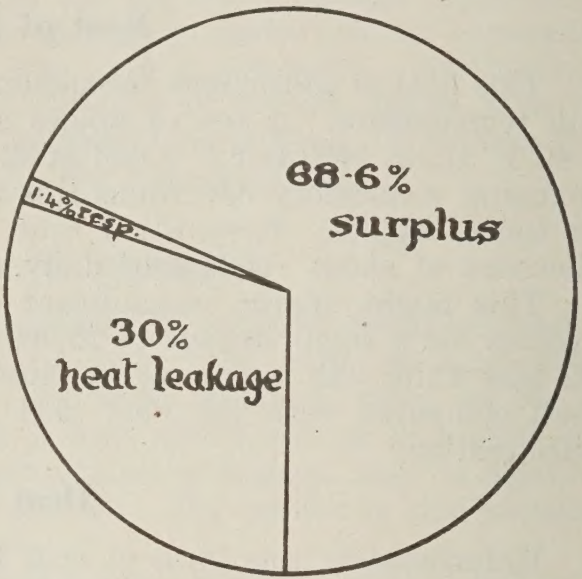


FIG. 2. Distribution of heat load, on left (A) at loading time and right (B) after the load is cooled. These figures are calculated on theoretical conditions which according to practical observations are typical.

Cooling Equipment

The preceding sections have dealt with heat loads or the work which must be done. The next consideration is one of ways and means for doing this work.

The least expensive means is to cool the apples with outside air. The weakness of this method is that its success depends on weather conditions. In spite of this, fairly satisfactory results may be obtained by using outside air for cooling. Careful management is essential to take advantage of cool nights and days. Even so, a long warm fall will occasionally cause insurmountable difficulties.

If it is planned to use this form of cooling for late apple varieties a well insulated building is the first essential. Rapid and uniform air exchange is best carried out by the use of a fan. This should be capable of changing the air in the storage every three minutes. Care should be taken to stop the air exchange system when the outside air is warmer than the apples.

The second in cost is the method of using ice to cool the storage. This involves the use of an ice bunker over which the air from the storage circulates either by fan or convection. In order to obtain maximum efficiency costly air circulation and bunkers are required to melt the ice rapidly enough to produce sufficient cooling. This method is seldom used.

Mechanical refrigeration is more expensive; but is by all means the most satisfactory if properly applied. In spite of the high cost mechanical refrigeration is being found in many apple growing areas to be an absolute essential to the industry. The reason for this is that refrigeration developed by mechanical means is easily controlled and operates more or less independently of weather conditions.

Fundamentally this form of refrigeration depends on cooling by evaporation. Certain liquids called refrigerants, require a large amount of heat in the process of evaporation. By thus absorbing heat, cooling is produced. Ammonia

is the most common commercial refrigerant, particularly in larger installations. The principle of refrigeration might be more easily understood by consulting Fig. 3.

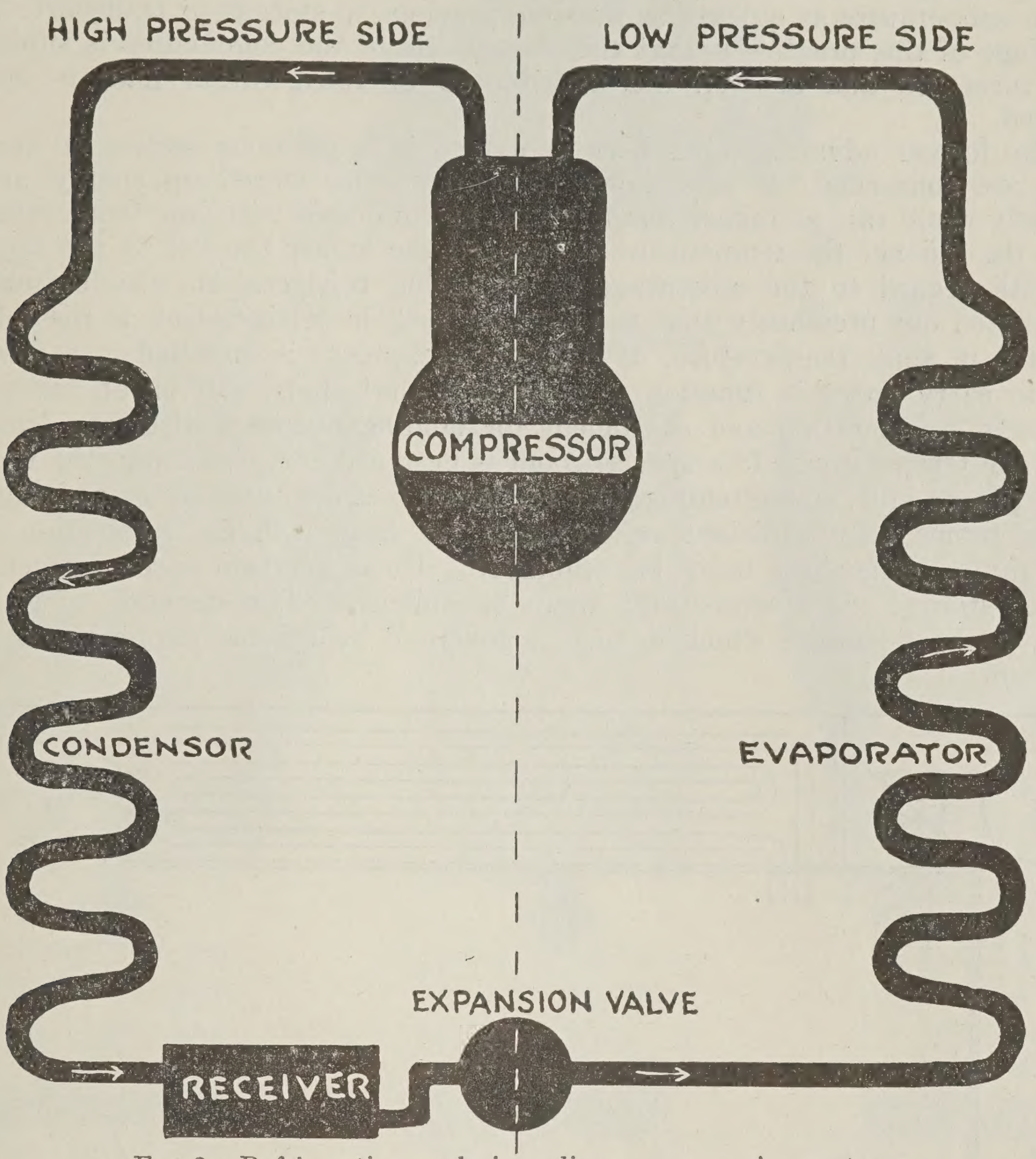


FIG. 3. Refrigeration cycle in ordinary compression system.

Liquid ammonia in the receiver being under pressure goes through the expansion valve. Here it evaporates under low pressure existing in the evaporator where cooling is produced. The compressor, which is nothing more or less than a circulating pump, pumps the gas out of the evaporator into the condensor. In the condensor, heat is given off, changing the refrigerant from a gas to a liquid when it passes back to the receiver and the cycle is repeated. There are three main adaptations for utilizing the refrigeration effect produced in the evaporator. When the evaporator consists of coils of pipe in the storage room it is referred to as direct expansion. In the brine circulation type the evaporating coils are immersed in a brine (usually calcium chloride) tank. This cooled brine is circulated through pipes in the storage room. Thus the brine acts as a vehicle for carrying refrigeration from the evaporator to the storage room. The third adaptation which is rapidly becoming more popular in apple storage is the wetted coil (or brine spray) air circulation system. In this system air, circulated by a fan, is cooled while passing over the evaporator, which in turn is sprayed with brine. This cooled and conditioned air passes to the storage room either directly or via ducts.

Precooling

Precooling is the term applied to the process of reducing a commodity to storage temperature as quickly as possible previous to storage or transport. The advantage of this practice is that the storage life of the commodity is substantially increased and as well the distribution of refrigeration load is better balanced.

The former advantage has been explained in a previous section so far as apples are concerned. It was shown that apples use stored up energy at an extremely rapid rate at higher temperatures as compared with low temperatures. Hence the quicker the temperature is reduced the longer the life of the apples.

With regard to the advantage of balancing refrigeration distribution, it was pointed out previously that the heaviest task in refrigeration is the initial reduction in apple temperature. If sufficient equipment is installed in a storage room to carry out this function it is obvious that there will be an excessive amount of refrigeration and equipment for holding purposes after the fruit is at storage temperature. If a special room is designed for precooling, the apples can be placed in it, where temperature reduction is accomplished. In the storage holding rooms only sufficient refrigeration for heat leakage, respiration and other minor exigenices need be employed. Under certain circumstances a common storage or ice cooled unit might be sufficient. This depends, of course, mainly on heat leakage which in turn is governed by outside temperatures and insulation.

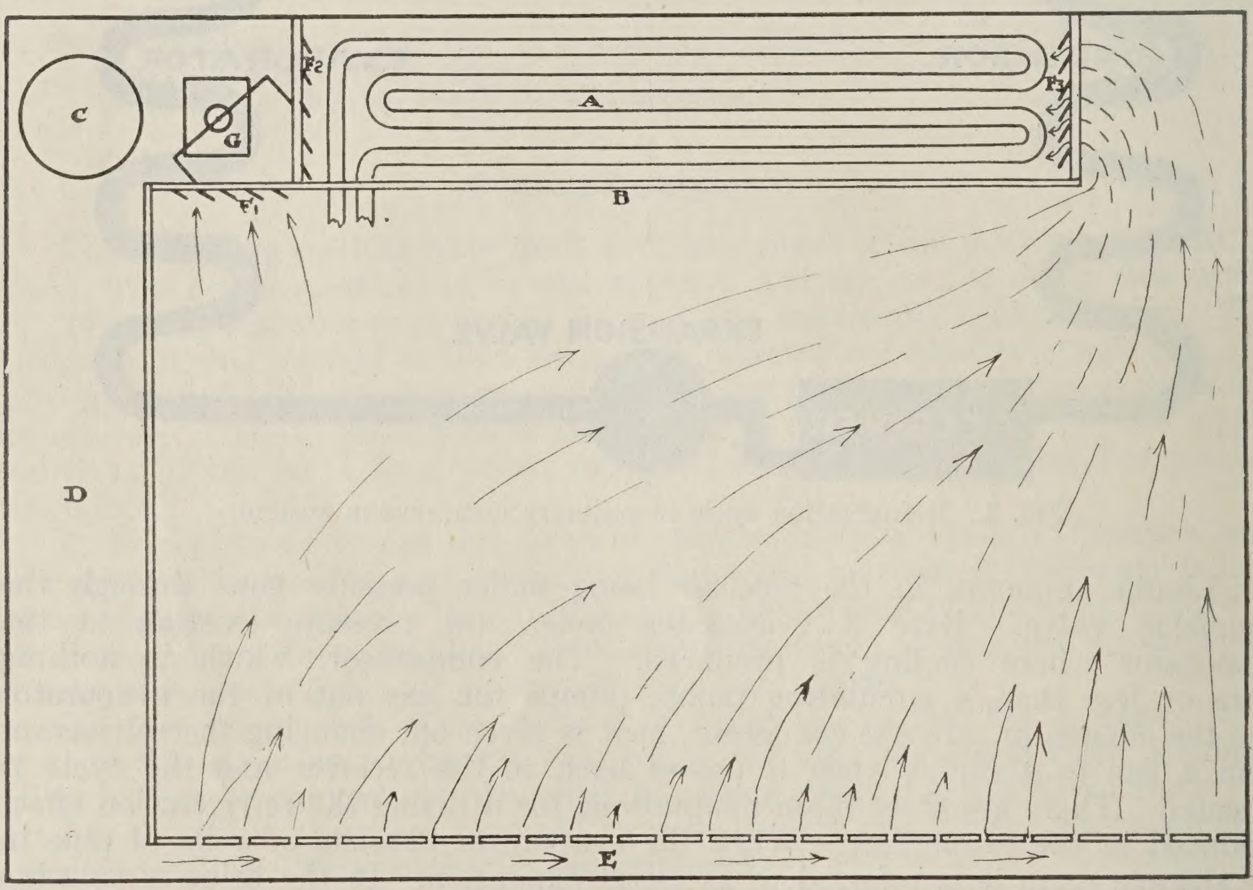
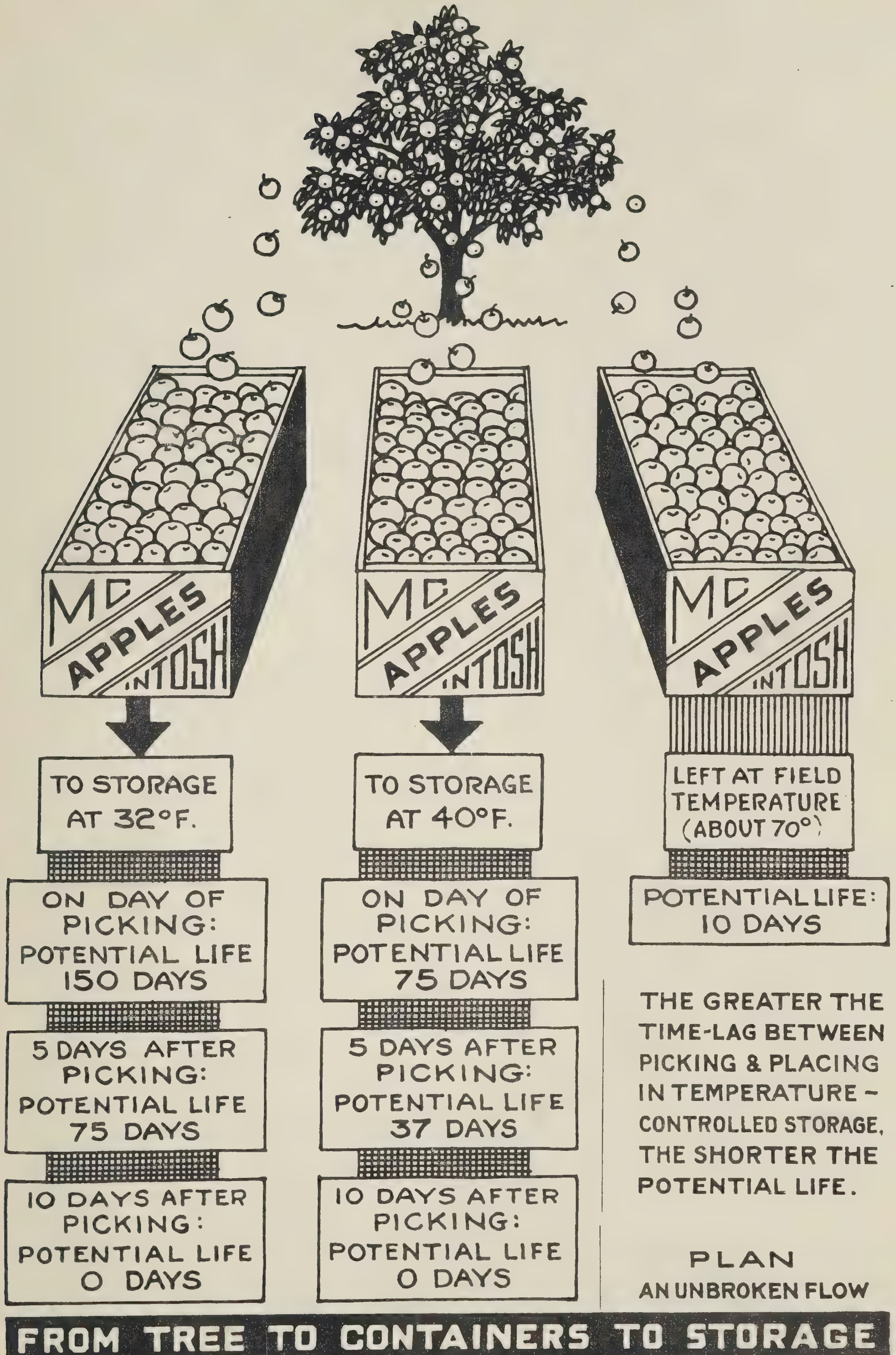


FIG. 4. Sectional diagram of precooler as designed and used at the Division of Horticulture, Central Experimental Farm, Ottawa.

The Division of Horticulture has done some considerable research on precooling equipment. After considerable investigation the under-floor-forced-ventilation system with overhead bunker was deemed best.

This has been in operation for several years and has been found satisfactory. A diagram of this setup can be seen in Fig 4. This consists of a room


MC APPLES INTOSH
MC APPLES INTOSH
MC APPLES INTOSH
TO STORAGE AT 32°F.
ON DAY OF PICKING: POTENTIAL LIFE 150 DAYS
5 DAYS AFTER PICKING: POTENTIAL LIFE 75 DAYS
10 DAYS AFTER PICKING: POTENTIAL LIFE 0 DAYS
TO STORAGE AT 40°F.
ON DAY OF PICKING: POTENTIAL LIFE 75 DAYS
5 DAYS AFTER PICKING: POTENTIAL LIFE 37 DAYS
10 DAYS AFTER PICKING: POTENTIAL LIFE 0 DAYS
LEFT AT FIELD TEMPERATURE (ABOUT 70°)
POTENTIAL LIFE: 10 DAYS
THE GREATER THE TIME-LAG BETWEEN PICKING & PLACING IN TEMPERATURE - CONTROLLED STORAGE, THE SHORTER THE POTENTIAL LIFE.
PLAN AN UNBROKEN FLOW
FROM TREE TO CONTAINERS TO STORAGE

of approximately 2000 cubic feet capacity in which is installed a cooling unit (A). This comprises 400 feet of $1\frac{1}{4}''$ ammonia piping (174 square feet). The ammonia is fed by a thermo expansion valve to these pipes. This unit is enclosed by bunker B. Bunker temperature is controlled by a thermostat operating liquid and suction stop valves on unit A. A fan (C) draws cooled air from this unit and delivers it at a rate of 6000 C.F.M. via duct D to the space E under a false floor. This floor is made of 2″x 4″ lumber laid at right angles to the air flow. These 2x4's are spaced to leave a small slit between. The spacing is adjusted in such a way that a slight static pressure is built up in E. This assures even distribution of cool air through all parts of the floor.

Temperature control of the room itself is carried out by modulating louvres F_1 and F_2, which are actuated by a thermostatically operated motor (G). When the precooler temperature is higher than the desired setting air is drawn through the bunker B via louvre F_2 and passes through the pre-described route. When the temperature approaches the desired point louvre F_1 opens slightly and F_2 closes to the same extent as F_1 opens. If the temperature in the precooler continues to drop F_1 opens more and F_2 continues to close. This means that as the temperature drops an increasing percentage of the air is short-circuited through F_1 which is not cooled but is merely recirculated. Temperatures may be such that F_2 is completely closed and F_1 completely open, in which case all the air is recirculated.

It can be seen from this description that maximum cooling effects can be derived from the cooling unit A without endangering the product by freezing.

Precooler Performance

If a precooler of the foregoing type is used the rate of cooling of the apples will depend on two main factors; (1) type of package and (2) method of stowage. For maximum efficiency both of these factors should be arranged to permit maximum heat removal from the apples.

In considering packages it is obvious that the apples in a large package will not cool so quickly as those in smaller packages. The reason for this is that in large packages a smaller percentage of the apples will be in contact with the walls of the container. Likewise, an open package will expose the apples to the air and thus bring about more rapid cooling than if the apples are in a completely closed package. The insulating properties of the container are also important. For example, corrugated paper-board containers of the same thickness as a wooden container would cool more slowly. This latter factor is not particularly significant when compared with the air protecting properties of the container. In other words the most important factor when selecting a package for precooling is to select one which allows a maximum of air to come in contact with the fruit.

The same principles apply to the stowage of the containers. If the containers are stowed directly on top of each other the cooled air coming from the floor can only come in contact with the sides of the container except, of course, for the bottom tier. If the containers are stowed too tightly, air flow again will be hampered. For maximum air contact, the packages should not be touching others alongside. Successive tiers should be built up so that each container is above the air space of the tier below.

Special containers and the prescribed method of stowage, of course, may be impracticable in many situations. Furthermore, the design and shape of the packages or other factors may be such as to make the prescribed method of stowage impracticable. Nevertheless these factors should be considered and an attempt made to achieve them as nearly as possible.

In Fig. 5 can be seen the actual performance of the precooler previously described in Fig. 4. This chart illustrates the rate of cooling of 200 bushels of Bartlett pears packed in bushel hampers with liners and pads. Temperatures recorded are internal fruit temperatures of pears situated at the centre of the hamper at various points throughout the load. The maximum temperature represents the highest or slowest cooling fruit in the load and the minimum is the lowest or fastest cooling points recorded.

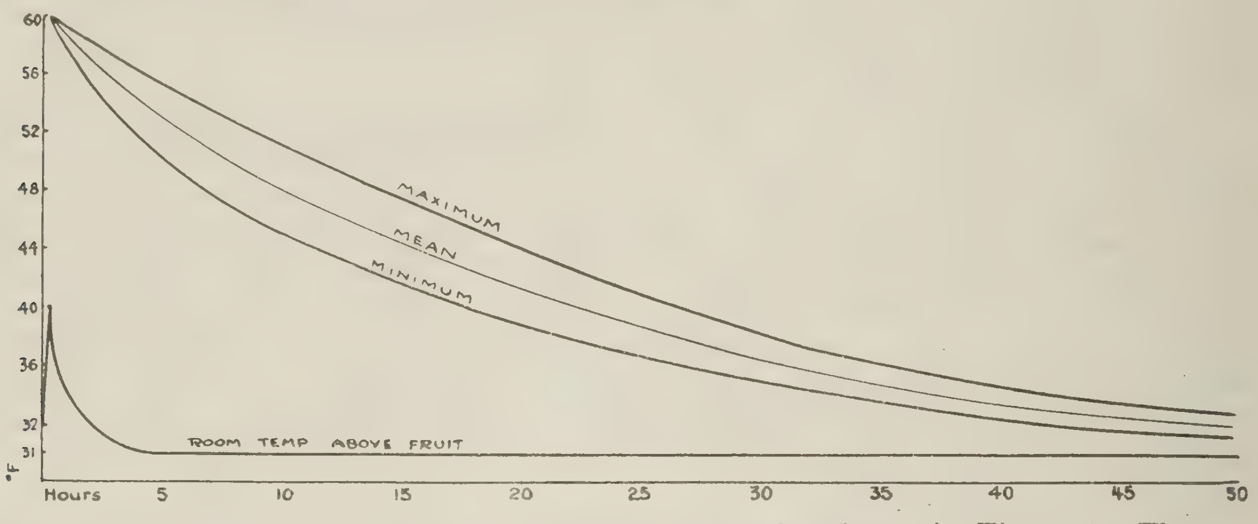


FIG. 5. Cooling rates of Bartlett pears in precooler shown in Figure 4. The temperature trends represent condition inside fruit at the centre of bushel hampers with top pads and liners.

On further observation it will be seen that the fruit harvest temperature was 60°F. In slightly over twenty-four hours the mean temperature was down to 40°F. which means that rapid high-temperature metabolism was practically reduced the first day. In forty-eight hours all the fruit was very close to the desired storage temperature of 32°F.

The fruit was then transferred to a 32°F. storage temperature without any disturbance to the room temperature. In this manner maximum advantage of storage temperatures was obtained with a probable two to three weeks extension of storage life over what is usually considered "good" commercial storage conditions.

It should be remembered that the previously described rapid, dry, air circulation method of precooling should not be applied to long storage. The reason for this is that the necessary rapid flow of dry air increases evaporation, resulting in considerable drying of the product. If the temperatures are watched closely and the product removed as soon as the temperature is down, the resulting damage has been found to be negligible in comparison with the advantages gained in rapid cooling.

Humidity

The main reason for regulating humidity (moisture content of the air) in storage is to control evaporation from the apples. Evaporation of moisture from apples results in loss of flavour, dry texture and shrivelling. It is not uncommon to see apples for sale in this condition, particularly during the latter part of the season.

In order to solve the problem it is necessary for the storage operator to have some knowledge as to the physics involved. When liquids evaporate they merely change to a gas and pass into the surrounding atmosphere. The liquid will continue to evaporate until the air in contact with the liquid has taken up all it can hold. When the air has reached this point it is said to be saturated or to have a relative humidity of 100 per cent.

A somewhat complicating feature is that warm air can hold more moisture than cold air. For example, a given volume of air may have a high relative humidity at 60°F. This air, however, may be cooled by coming in contact with a colder surface such as a window pane in a house or cooling coils in a storage. This drop in temperature makes the air less able to hold moisture. The result is the presence of water or frost on the cooler surface. This function of moisture removal from air by lowering the temperature is called condensation.

How is this related to apple storage? In the first place apples contain a large proportion of water, 76·6 to 86·5 per cent.

If part of this water is lost the skin will become wrinkled and the flesh will feel spongy. Furthermore, losses of moisture are usually accompanied by losses in flavour. It is evident, therefore, that all possible precautions should be taken to prevent the loss of moisture from apples. It may be further stated that once moisture is lost from apples there is no practicable treatment or procedure which will bring the apples back to their original fresh condition.

The water in apples is mostly contained within the cells making up the flesh of the apple. These cells are in contact with air inside these tissues. This air in turn passes to the outside by way of small pores on the skin surface called lenticels.

When an apple is placed in storage it is obvious that the moisture content of the air surrounding the apples is going to have considerable influence on the moisture content of this fruit. For example, the relative humidity of the air may be 50 per cent. When a portion of this air enters the apple through the skin it comes in contact with the cells. This air because of its dryness takes moisture from the cell until it is very nearly saturated. This moisture-laden air then passes out of the apple to the storage atmosphere, resulting in evaporation or moisture loss from the apple. If moisture loss stopped when the storage air became saturated it would be satisfactory. Instead, this saturated air may be chilled by coming in contact with a cold wall or cooling unit, resulting in condensation in the form of drip or frost. When the temperature of this air is raised again it is ready to absorb additional moisture from the apples.

Another form of moisture loss may be caused by the packages. Instead of being chilled the moisture laden air from the apples may come in contact with dry wooden containers or other substances which may absorb moisture. This tends to dry the air and increase its capacity for taking moisture from the fruit. The chief cause of controllable moisture loss in apples, however, is from condensation on cooling pipes or units. It may be assumed, for example, that a storage room is operating at 35°F. and the temperature of the cooling surface is 20°F. Air coming from the apples at about 98 per cent relative humidity at 35°F. will be reduced to about 55 per cent relative humidity after passing over the cooling coils when the temperature is again increased to 35°F.

In Fig. 6 the principle of moisture loss by cooling pipes is illustrated. It will be noted that the load of apples is held at 35°F. Because of heat generated by the apples, the air passing off will be slightly higher than 35°F. and will be laden with moisture from the apples. On reaching the cooling coils the air (at least a portion of it) will be reduced close to 20°F. (the temperature of the cooling surface). This reduction in temperature brings about condensation resulting in drip or frost on the coils. When this air is raised to 35°F. by coming in contact with the fruit (or other air) its moisture-holding capacity is restored and therefore it takes more moisture from the apples, which in turn is deposited on the cooling coils.

Measuring Relative Humidity

Instruments based on temperature reduction by water evaporation are usually used for measuring relative humidity. This is done by having two thermometers which are very carefully matched with regard to temperature reading. Moisture is permitted to evaporate from the surface of the bulb of one thermometer and the other remains dry. This instrument is known as a wet and dry bulb thermometer. The drier the air the more rapidly the water will evaporate from the wet bulb of the thermometer and thus bring about a reduction in temperature below that of the dry bulb. By consulting a chart usually supplied with the instrument, the relative humidity can be determined by knowing the wet and dry bulb temperatures.

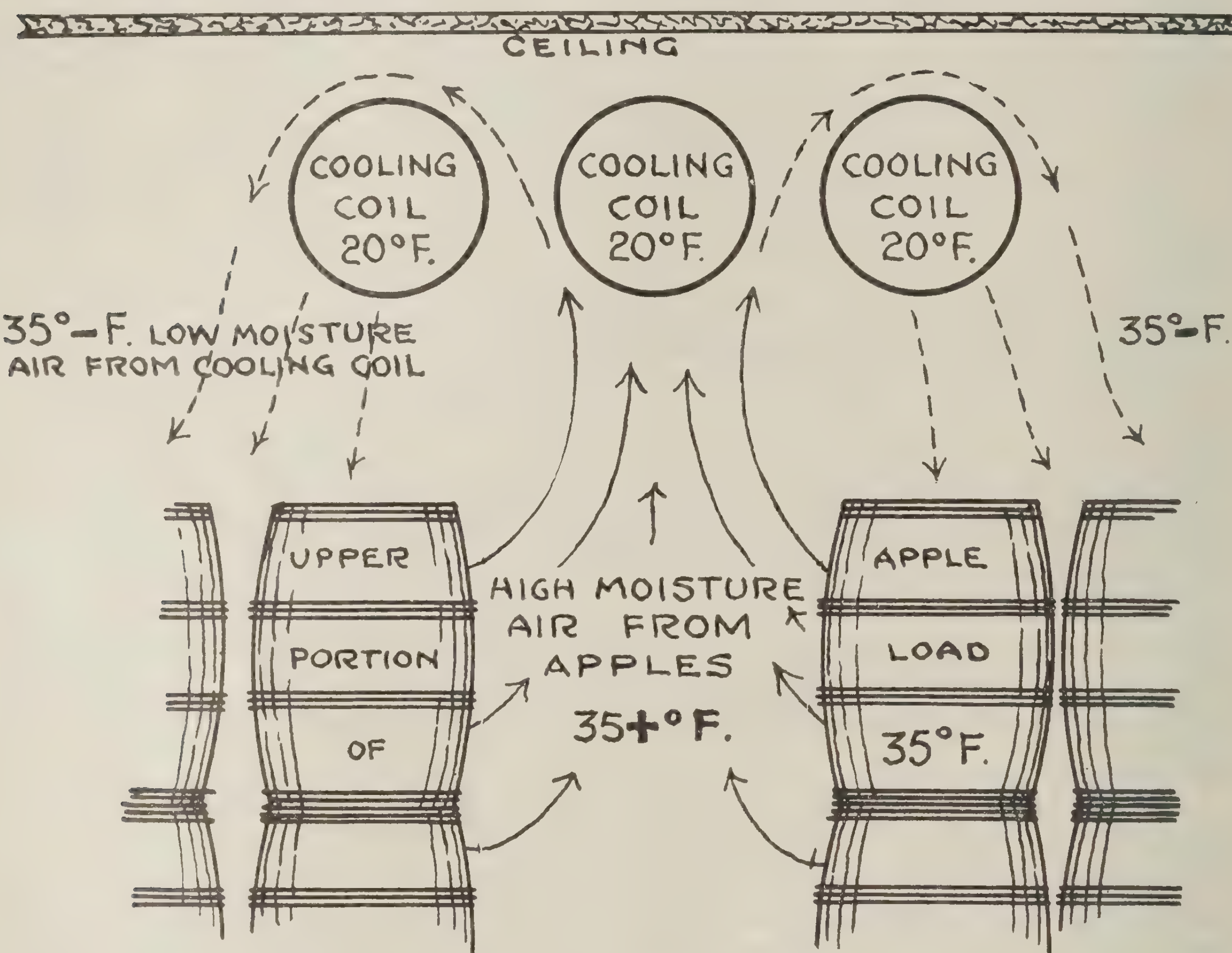


FIG. 6. Diagramatic illustration showing the principle of moisture loss on cooling pipes in storage.

In order to obtain accurate temperature readings the air flow over these bulbs must be fairly rapid. This is effected by swinging the thermometers in a circular motion, as with the sling psychrometer (see Fig. 7) or forcing air over the thermometer bulbs as in the hand-aspirated psychrometer. The latter type is usually more satisfactory, particularly because it is not so likely to be damaged in operation as is the case with the sling psychrometer. Both are found to be fairly satisfactory when readings within 2 to 3 per cent accuracy are required.

There are other devices used for indicating relative humidity, such as the ordinary wet and dry bulb thermometer, the hair hygrometer, the dew-point apparatus and others. By close observation, however, it has been found that the hand-aspirated or the sling psychrometer of reliable manufacture are the most practical and reliable.

What is important, however, is what is to be done, if the humidity is too high or too low. For average commercial apple storage it has been found that 90 per cent relative humidity is satisfactory. Under ordinary circumstances a moderately well filled storage room will reach this point if the temperature control is reasonably good and there is no appreciable moisture loss.

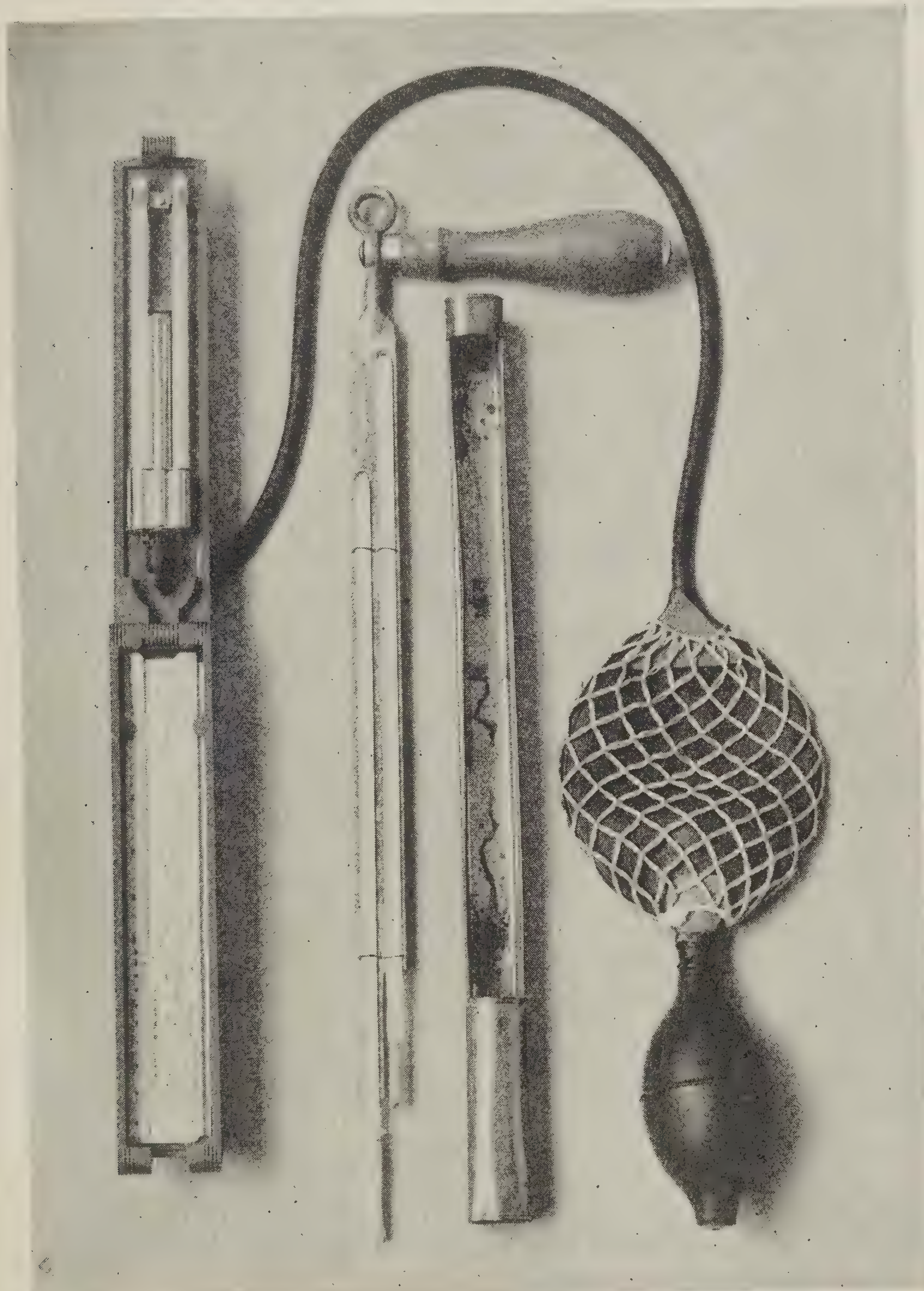


FIG. 7. Wet and dry bulb instruments for determining relative humidity. On left is hand aspirated type with squeeze bulb attached. In centre is sling psychrometer type.

If the relative humidity is much below this level, it is wise to first investigate the temperature of the surface of the cooling unit. The best indication of too great a temperature differential between cooling surface and storage room temperatures is frost accumulation on the cooling surface pipes or coils. It is possible by increasing the cooling surface and increasing the temperature of the refrigerant to avoid frost or moisture accumulation almost entirely.

Once it has been established that the cooling surface is not robbing moisture from the air, the next step is to check the walls of the storage. Insufficient insulation will tend to reduce relative humidity by robbing the air of moisture by condensation. Evidence of this will be seen by examining the surfaces for frost or drip. Another point to consider is the moisture barrier covering the insulation. If this is suspected of being faulty, the insulation material should be examined. This is done by cutting into the wall at various points. If the insulation is wet it should be thoroughly dried and the surface moisture-proofed with asphalt compound, paper or other material.

It should not be expected that the relative humidity will be high when the storage room is only partially filled with apples. When the storage is half filled or less, sprinkling the floors or other methods of adding moisture to the air will be helpful in maintaining the proper moisture level.

Excessive relative humidity is seldom a problem. If this condition does occur it can be remedied by reducing the coil surface and increasing the temperature differential.

STORAGE LIFE OF APPLES

The influence of maturity on storage life is sufficiently important to warrant repetition. As mentioned previously, maturity at storage loading and harvest is the most critical single factor contributing to good storage results.

The living processes in the apple go through a definite cycle. This cycle is characterized by changes in skin ground colour from green to yellow, reduction in starch concentration as indicated by the iodine test, changes in sugars and aromatics indicated by flavour. Seed colour indicates maturity of seeds and may or may not be an indication of the maturity of the apple. This cycle is controlled by complicated physiological factors.

While attached to the tree the apple draws nourishment and is influenced by conditions in the tree and soil. On detachment at harvest the apple becomes a separate and independent unit. It is not surprising then that the position in the ripening cycle is important. It is important to know at which stage the apple can be harvested and provide both long storage and full flavour. Going into the subject more deeply it is found that the main food energy used by the apple is sugar or chemically related substances. In the earlier stages on the tree the sugar is concentrated to starch by condensation processes. When food supplies from the tree are inadequate to supply the normal needs of the fruit this reserve supply of starch is re-converted to sugar, which in turn is used to maintain life.

Thus it would appear logical that when maximum starch content is obtained in the apple it would have reached maximum capacity for storage. This is true except in some varieties. The ability of the fruit to ripen further does not coincide with this point. What then is to be used as a criterion for determining the point of maximum storage ability?

So far the most satisfactory answer to this question has been the respiration curve. When sugar is used up in the cells of the apple it is changed to carbon dioxide and water. It is the chemical energy released in this process which

maintains life. Thus, if carbon dioxide output can be measured, the rate at which sugar is being used up can be calculated or in other words a measurement of respiration rate is obtained.

Respiration Rates and Curves

Fig. 8 shows the rate at which McIntosh apples respire under ordinary temperature conditions. It will be seen that there are three phases, (1) growing, (2) maturing and (3) storage. If McIntosh apples are harvested in phase 1 the ground colour will be very green, the apples will shrivel in storage, and fail to mature normally. If harvested at the beginning of phase 2, similar but slightly improved results will be obtained. The best results, however, can be obtained at the end of phase 2. It is at this point that rapid changes from green to yellow ground colour are noted.

There appears to be a definite change in the type of metabolism from the maturing phase to the storage phase. This conclusion has been reached from observations of McIntosh apples under various circumstances. If apples are harvested in the maturing phase (phase 2, Fig. 8) and are cooled immediately to 32°F. core flush is almost certain to develop. Likewise, exposure to methyl bromide in this phase is more likely to produce injury. Even in gas storage carbon dioxide injury is much more likely to occur in this phase. By allowing the apples to pass into the storage phase (phase 3, Fig. 3) the previously mentioned troubles are eliminated.

It would appear then that if McIntosh apples were harvested at the beginning of the storage phase, best storage results could be obtained. Actually the best time of harvest is at or slightly after the critical point marked on Fig. 8. If harvested at this time the small remaining portion of the maturing phase is finished before the temperature of the apples is reduced to that of the storage (32°F.) The colour chart prepared by the Division of Horticulture was designed so that the fruit grower could determine this point himself.

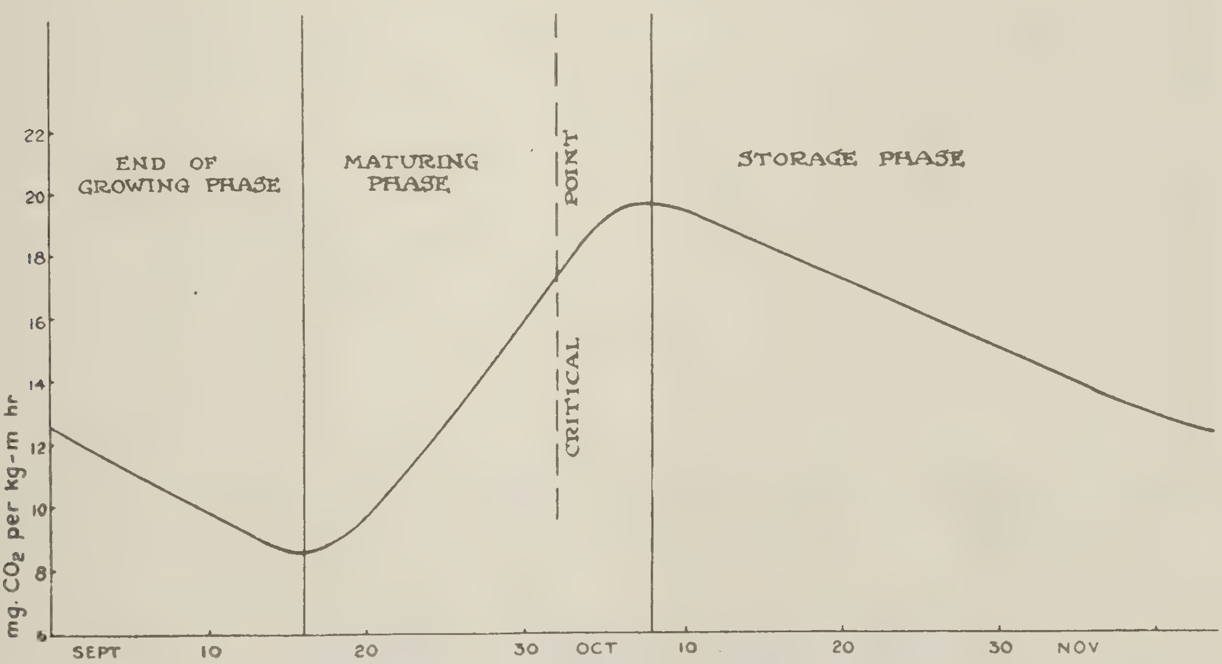


Fig. 8. Trend of respiration in McIntosh apples throughout the harvesting period. Note the critical point near the end of September. For highest quality this point should be reached before harvest.

From a practical standpoint it is not always possible to adhere to maturity recommendations because of difficulty in obtaining the necessary help, weather conditions or other reasons. The best solution for this difficulty is to segregate

the apples at harvest and allow the immature fruit to ripen slightly before storing. Over-mature fruit should be cooled immediately and marketed early. The apples harvested at the correct stage should be given the most consideration because they are the ones that should be used for the most select trade since they will develop maximum quality.

The Effect of Temperature on Respiration Rates

When the respiration curve (Fig. 8) is studies it will be noted that aging of the apple is characterized by two features, one being a change in rate and the other a change in the form of the curve. These features are very similar, nevertheless both serve as independant criteria of the apple's development.

When apples are exposed to low temperatures the tendency is to flatten out the whole curve. The climateric or hump is less accentuated and the degree of slope in the storage phase is not so steep. In other words the effect of lowering the temperature slows down the rate of metabolism and, as well, slows down the rate of aging. Rate of aging may be a direct result of a lowering of metabolism but other contributing factors indicate that this is only partly true. The effect is too complicated for such a simple explanation. There is a similarity between temperature effect on maturity as compared with rate of metabolism but the agreement is not perfect. For example, the rate of carbon dioxide output at 46°F. is approximately twice what it is at 37°F., but the storage life is not necessarily half as long at the higher temperature.

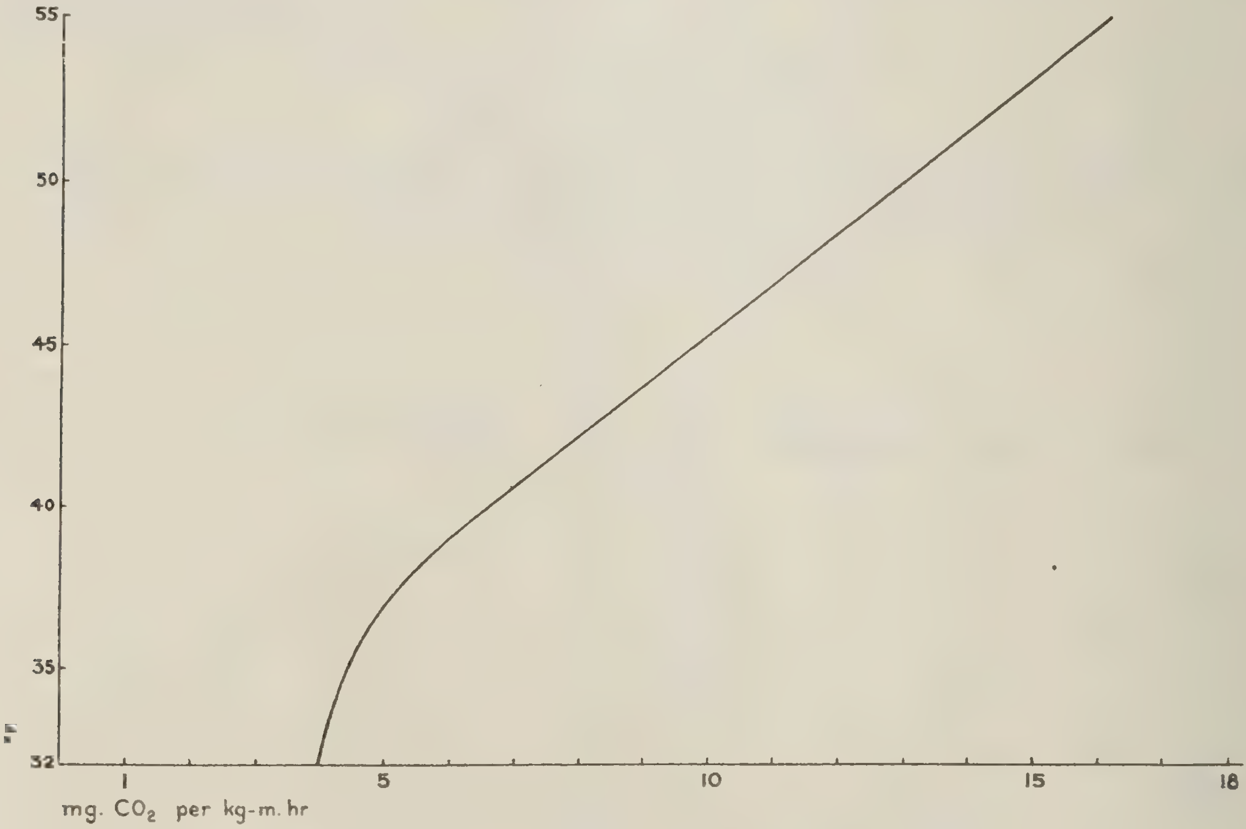


FIG. 9. Respiration rate of McIntosh apples at various temperatures.

Quality Trends in Storage (McIntosh)

Fig. 9 gives the rate of carbon dioxide output of McIntosh apples at temperatures ranging from 32°F. to 55°F. These values were established in the post-climacteric phase on the same apples after allowance was made for normal drift. This gives as true a picture of temperature effect as it is possible to get.

The important point brought out in Fig. 9 is that decreases in temperature down to 39·F. show a marked reduction in carbon dioxide output. Below this

temperature a smaller reduction in carbon dioxide is obtained for each proportionate decrease in temperature. The practical value of this information is that the more rapidly the temperature of McIntosh apples is dropped to 40°F. or less the better. The rapidity of subsequent decreases in temperature is not nearly so important. This rule applies with modification to other varieties. It is also interesting to note that this temperature (40°F) appears to be the approximate critical temperature for core flush development. As noted elsewhere immature McIntosh apples develop core flush at 36°F. and below whereas no core flush develops at 39°F. or above during the normal storage life.

By quality is usually meant the combination of factors such as texture and various flavours which contribute towards the acceptability of the apple. The development and retention of quality are the most important considerations in apple storage but on the other hand are the most difficult to evaluate.

Maximum quality in McIntosh apples has been arbitrarily set as being represented by an apple having a crisp texture and slight acidity accompanied by high aromatic flavours. At harvest the texture is usually slightly lumpy or woody. This changes to a crisp texture followed by a mellow condition and finally the texture becomes mealy and dry. Flavours change from acid to sweet by degrees until the acidity entirely disappears leaving only a flat sweet flavour. Aromatic flavours which give character to any variety are hardest to define. These develop rapidly after harvest and disappear just as rapidly if careful storage is not carried out.

It is these facts that make quality difficult to evaluate. Another point is that quality cannot be measured mechanically. The only way to determine quality is by taste which varies from time to time in the same individual and, of course, there is extreme variation between individuals. In spite of these difficulties an evaluation of quality has been attempted which shows reasonable consistency and reliability. The tasters based their evaluation on a total score of ten. Deductions from this total score were made on the following basis:

Texture—		
crisp	0	
mellow	2	
woody or lumpy	2	(if the apple otherwise was not ripe)
slightly mealy	5	
mealy	8	
Flavour—		
acid, no aroma	2	
aromatic, sweet	0	
aromatic, slightly acid	0	
moderately aromatic	1	
slightly aromatic	3	
insipid—sweet	4	
insipid	5	
any mal flavour	10	

If the apple taster classed an apple as being mellow, slightly aromatic it would have a score of 5 (10—2—3=5). Thus it can be seen that apples below a 5 score would be objectionable and should not be marketed as first class fruit. On the other hand a score of 7 or more indicates good quality.

From Fig. 10 can be seen the trend of eating quality of McIntosh apples at three different storage temperatures (32, 36, 39°F.). One feature with regard to effect of temperature variation is that low temperature, 32°F., tends to maintain good texture at a slight sacrifice of flavour development. If McIntosh apples are reduced to 32°F. previous to the development of aromatic flavours these will not develop to the same extent as at 36°F. or 39°F. Another noticeable feature with McIntosh is that at 32°F. colour change from green to yellow is not nearly so rapid as at the higher temperatures. As a matter of fact if harvested too green no colour change will take place throughout the storage life at this

temperature. On the other hand high temperatures sacrifice texture retention for flavour development. Apples at 36°F. and 39°F. tend to become mellow and mealy while still possessing a reasonable amount of flavour.

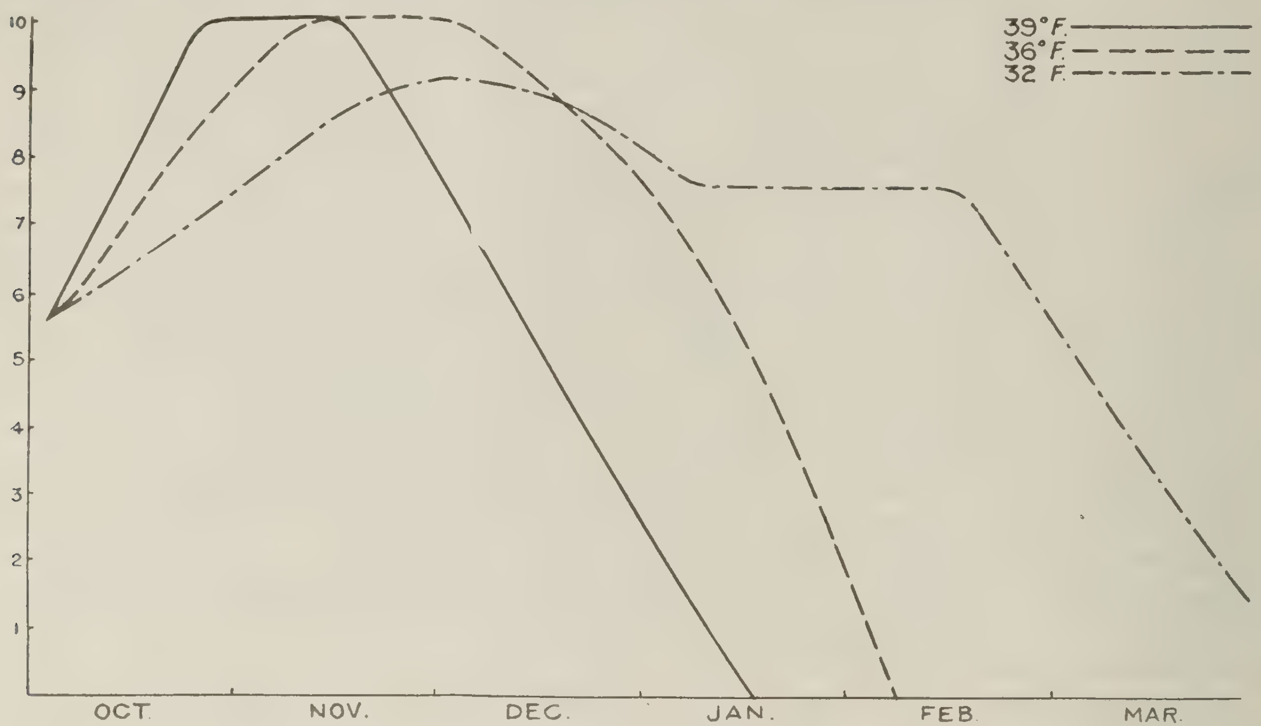


Fig. 10. Approximate trend of eating quality of McIntosh apples at three different storage temperatures. (Maximum quality 10)

When considering the general quality trends in Figure 6 it will be noted that the 32°F. curve takes a different trend than does the 36·F. or 39°F. curves At no time does quality reach the maximum of 10 at 32°F. Maximum quality is reached during December which shows a gradual decline to a value of 7. This is maintained well into February, after which a rapid falling off is noted. At 36°F. and 39°F. a more rapid progress towards a maximum of 10 is seen. This is maintained for a relatively short period after which a rapid drop in quality is noted.

The end of storage life so far as quality is concerned should be at the point where quality values show a rapid drop. An absolute limit is when the value of 5 is reached. These two points for each temperature are as follows:

39°F. end of November—middle of December
36°F. first week of December—middle of January
32°F. middle of February—first of March

It must be kept in mind, however, that these points will be influenced by pre-storage factors, method of storage, type of containers, etc. Furthermore, although this marks the end of storage life as governed by quality, the apples may still have an excellent appearance. It is indeed unfortunate that this latter type of apple is marketed, since it can produce nothing more than disappointment and dissatisfaction to the consumer.

So far as other varieties are concerned it is probable that quality trends will assume a similar form, the chief difference, of course, being the time factor. It must also be remembered that varieties which normally possess stronger flavours can afford to lose much more quality before becoming objectionable.

Onset of Physiological Disorders

Under a previous heading on respiration rates in storage it was mentioned that carbon dioxide was given off as a final product of metabolism. This, of course, does not represent a simple chemical reaction but a series of many reac-

tions. Under normal circumstances the reserve material in these metabolic reactions is starch. This in turn is converted to various sugars which are oxidized into more simple compounds and which finally escape in the form of carbon dioxide and water. The picture is further complicated by the entrance of acids and other chemical compounds. All these reactions are delicately controlled by enzymes.

It is reasonable to suppose then that if these reactions are slowed down by exposure to low temperature, complicated results are likely to ensue. For example, if the sugar reactions are slowed down more than the starch a build-up of sugars will result. This surplus instead of accumulating may enter into another phase of reactions resulting in the formation of deleterious substances. Or the reverse temperature effect may be produced in which a scarcity of sugars may occur and the apple in order to carry on may break down materials essential to the structure of the cells, which result would also be deleterious.

When apples are placed in cold storage and breakdown occurs it can quite frequently be explained on these principles. For example, superficial scald has been shown to be damage to the skin cells by the presence of acetaldehyde. This acetaldehyde was produced by the tissues themselves and, being toxic, destroyed the skin cells. Normally at higher temperatures this substance would not have been produced. This is an example of a physiological disorder resulting from exposure to low temperatures. Thus it is that in many varieties physiological disorders terminate storage life. Among these disorders are, superficial scald, core flush, low temperature breakdown, etc. Suggested methods of control, descriptions and further details will be found in another bulletin on Functional Disorders of Apples.*

STORAGE ATMOSPHERE

Atmospheric conditions in the storage play an important part in the success or failure in holding apples. The atmosphere consists essentially of nitrogen, oxygen and small amounts of carbon dioxide. Added to this there is a varying quantity of water, which has been discussed under the section on humidity. In addition, air in the storage may be contaminated with gases given off by the apples, moulds or other substances. These in turn may be absorbed by the apple tissues, resulting in mal flavours or disorders.

Tainting of apples is not so common as with dairy products, particularly cream and butter. With the latter products the apples are usually the offenders. Fats are good absorbents. When apples are stored with butter the latter may take on an "apple" flavour. Apples, however, have been known to take on a potato flavour when stored with them. The most common form of tainting, however, is with moulds. When rotted apples are allowed to lie around and the storage becomes musty the sound apples will be affected.

Practically all living material gives off volatile substances. These substances may or may not be objectionable from a taste standpoint. Then the first logical step is to store only one kind of commodity in the same room. All moulds and rots should be controlled or removed. Maintaining a fresh, clean storage pays dividends in this respect.

Another form of injury brought about by other gases in the air is from a physiological standpoint. It has long been known that ethylene gas will ripen tomatoes, bananas and other fruit. Ethylene is produced by apples (as in other fruits) when ripe. It has been known that ripe apples in storage hasten the ripening development of less mature fruit. This is not definitely known to be serious in Canada. On the other hand it is better to separate less advanced apples from the ones which are more mature if ripening is to be retarded.

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*Functional Disorders of Apples, C. A. Eaves and H. Hill—Pub. 694 Technical Bul. 28. Dominion of Canada, Department of Agriculture.

Controlled Atmosphere Storage (Gas Storage)

This type of storage merely consists of using a higher concentration of carbon dioxide and lower concentration of oxygen than is normally found in air for the preservation of fruits. These atmospheric conditions are generally used in combination with refrigeration or low temperatures. It has been pointed out that apples give off carbon dioxide and take in oxygen in their normal metabolism. If these metabolic processes can be slowed down, as happens with low temperature storage, life is prolonged. It has been found that increased carbon dioxide and reduced oxygen have an effect similar to that of temperature reduction. Like temperature, however, these conditions must be controlled.

The practical method of applying this principle of abnormal atmosphere for preservation is simply to enclose the fruit in a gastight, refrigerated room. Some sort of control is also necessary. This is accomplished by having apparatus which determines the concentration of gases and a simple, controlled, ventilating device. Fundamentally that is all that is necessary in the construction of a controlled atmosphere storage.

In the matter of operation one makes daily determinations of carbon dioxide and occasionally oxygen content. When the concentration of these gases reaches the prescribed point for the variety of fruit involved, ventilation is carried out by starting a small fan. Further details in connection with the construction and operation of this method of storage will be subsequently outlined.

Advantages of Controlled Atmosphere Storage

The benefits to be derived from this form of storage are numerous and varied. The prolongation of storage life is the one advantage that occurs first (though not necessarily the most important) to the storage operator. According to experimental results with the McIntosh variety, apples were removed from gas storage at 39°F. in February in prime condition. Previous charts show that November is the latest month to which these conditions can be maintained in ordinary storage at this temperature. Furthermore, maximum quality is attained which is not usual for lower temperature storage.

Another, and probably more important advantage of controlled atmosphere storage is that physiological disorders associated with low temperature can be controlled without a reduction in storage life. For example, it has been difficult to hold Cox Orange Pippin at 32°F. until the end of December without inducing low-temperature breakdown (at higher temperatures the storage life is comparatively short). This variety has been successfully stored at 39°F. under controlled atmosphere well into January without low-temperature breakdown and with little loss in quality.

Another example of this nature is with the storage of McIntosh apples. Quite frequently this variety suffers from a physiological disorder known as core flush (see description under storage disorders). The trouble occurs more commonly with large soft apples which have been grown on young trees under high-nitrogen conditions.

Much experimental work has been done with the storage of McIntosh apples in controlled atmospheres with the object of controlling core flush. All the evidence obtained points to the possibility of practically complete control of this disorder in McIntosh by the use of controlled atmosphere. This has been accomplished with no sacrifice in storage life as compared with ordinary cold storage at 32°F. In other words if controlled atmosphere storage was used commercially McIntosh could be marketed just as long as under present conditions, or maybe longer, and the control of core flush would be assured. Typical of the results obtained are those found in Table 1. For 1937-38 these show a comparison between various sizes of apples from an orchard moderately sus-

ceptible to core flush. The 1938-39 results are from test plots which had produced very high percentages of core flush in the past. It will be noted in all instances core flush has been controlled. The only instance where core flush appeared is shown under "susceptible to core flush A" (Table 1). This material was grown on a plot receiving excessive amounts of nitrogen, which would not be applied in any commercial orchard. Even under these circumstances it is seen that the amount of core flush is small (4%).

Another disorder which is reduced in controlled atmosphere storage, is wilting or shrivelling. As pointed out under another heading moisture from the apple passes into the storage room. If this can be retained in the storage room further losses from the apple can be prevented. The two sources of loss are by condensation on the refrigeration pipes or cooling surface and passage through the walls or door to the outside. Since the room is sealed the latter avenue of moisture escape is blocked. Moisture removal through condensation can be corrected by mechanical means.

It has been found, too, that apples from controlled atmosphere storage stand up longer on removal from storage. During the latter part of January, McIntosh apples from ordinary storage usually show signs of mealiness and lack of flavour in about five days at 65°F. The same apples in controlled atmosphere, although appearing about the same on removal, require eight to nine days to reach the same stage as those held in ordinary storage.

Having mentioned the advantage or benefits of controlled atmosphere it is only reasonable to state the disadvantages. One somewhat debatable drawback is the development of superficial scald. It is generally believed that this disorder is more apparent in controlled atmosphere. This has been found true during certain years of experimentation. At any rate equally effective control is gained by the use of oil wraps or shredded oil paper. If apples are destined for controlled atmosphere storage it is even more advisable to use the oil paper treatment.

TABLE I—CONTROL OF CORE FLUSH IN McINTOSH APPLES BY CONTROLLED ATMOSPHERE STORAGE

Source of Material	Apple Size	Year	Type of Storage	Temp.	Storage Elapse before Examination	Core Flush Per Cent
Standard Orchard...........	$2\frac{1}{2}''$ and up	1937	ordinary	32°F	147 days	73·2
	$2\frac{1}{4}''—2\frac{1}{2}''$					35·0
	$2''—2\frac{1}{4}''$					16·0
	$2\frac{1}{2}''$ and up		controlled	39°F	147 days	0
	$2\frac{1}{4}''—2\frac{1}{2}''$		atmosphere			0
	$2''—2\frac{1}{4}''$					0
Susceptible to core flush—A.	$2\frac{1}{2}''—2\frac{3}{4}''$	1938	ordinary	32°F	116 days	38·0
	$2\frac{1}{2}''—2\frac{3}{4}''$		controlled atmosphere	39°F	116 days	4·0
B.	$2\frac{1}{2}''—2\frac{3}{4}''$	1938	ordinary	32°F	116 days	16·6
	$2\frac{1}{2}''—2\frac{3}{4}''$		controlled atmosphere	39°F	116 days	0

Another point is that once the room is sealed it must remain so for a long period. This means that the apples and the storage room cannot be examined during this time. If, however, good fruit is used and outside temperature indicators are used, no harm or inconvenience should result.

Selection of Gas Mixture

Just as temperature is the important factor in ordinary storage so is the concentration of carbon dioxide and oxygen in controlled atmosphere storage. The theory is that carbon dioxide acts much the same way as a narcotic or drug to the apple. Thus the metabolism is reduced to a low point in much the same way as in an individual when asleep or under the influence of certain drugs. Reduced oxygen slows down rate of metabolism but in a different way. Since most reactions involved require oxygen or are oxidative in nature, naturally a reduction in oxygen is going to slow down these reactions. The important factor then is to have this double effect of high carbon dioxide and reduced oxygen balanced in such a way as to do no harm to the apples.

The only practicable way to determine this point is to expose apples of different varieties, grown under various conditions, etc., to concentrations of carbon dioxide and oxygen throughout storage. On examination the gas mixture producing the best storage conditions can then be determined. This is the course of experimentation which has been followed. After determining the proper gas mixture on a small scale, larger scale semi-commercial trials are conducted and recommendation made accordingly.

From these results it has been learned that gas mixtures fall into two main groups; (1) normal gas mixtures and (2) sub-normal gas mixtures. In the former the increase in carbon dioxide is equal to the reduction in oxygen. In the latter the increase in carbon dioxide is much less than the decrease in oxygen. An easy method of differentiating these two groups is by totalling the carbon dioxide and oxygen. If it equals 21 then the mixture is normal; if below 21 it is sub-normal.

Normal gas mixtures are easier to obtain and require less rigid gas-tighting. This is because apples have a respiratory quotient of one; that is, for every unit of oxygen used an equal amount of carbon dioxide is given off. Thus, since there is approximately 21 per cent oxygen in the air, the sum of the percentages of carbon dioxide and oxygen in the sealed room will usually remain at 21. For example, if apples are placed in a sealed room until 7 per cent carbon dioxide accumulates the oxygen will be reduced to 14 per cent an equivalent amount (7%) of oxygen has been used by the apples.

On the other hand if a normal mixture is not satisfactory, as may happen, some of the carbon dioxide will have to be removed. This is usually done by means of a scrubber and is accomplished by passing the air from the storage room through a caustic soda spray until sufficient carbon dioxide has been removed to obtain the desired concentration of gas. This naturally results in a suction pressure within the room, necessitating a greater degree of gas-proofness.

Construction of the Gas Chamber

So far as general observations are concerned size is not an important factor from the standpoint of manipulation. If a large room is selected it just means that greater capacity is needed for ventilation or scrubbing. It is essential that some consideration be given to size, however.

In the first place the chamber or room should be as nearly completely filled as possible. This means that the ratio of volume of air to apples is reduced making it easier to attain the desired atmospheric conditions. Another point is that the ratio of room surface to fruit volume is also reduced. This is effective in making up for gas losses which may occur through inefficient gas tighting. In view of these considerations it is wise to select a room of a size which will ensure its being filled.

Another point is that controlled atmosphere storage is primarily used for the long storage holdings. Hence the room or rooms should be of a convenient size to hold the material destined for the later market.

Making the Chamber Gas Tight

There are two systems in use at the present time. The most efficient and most costly is metal lining. A 28-gauge sheet metal is effective and is essential for sub-normal atmospheres. As pointed out previously, these gas mixtures are induced by gas absorption, resulting in suction pressures in the room. The second system of gas tighting is by the application of gas tighting paints or sealing compounds. These are less costly and are quite effective for normal oxygen gas mixtures.

(1) Metal Lining.—The metal sheets are merely nailed to the studding with a $1\frac{1}{2}''$-$2''$ overlap. The joints are well sealed with caulking compound. Broad headed nails should be used and these, of course, should be puttied or sealed with a gas tighting compound. Only sufficient nails to make secure construction should be used; spacings of $1\frac{1}{2}$-$2\frac{1}{2}''$ should be ample. Instead of having the overlap nailed the joints can be soldered. If this is done a double lap roof type joint should be made to protect the seam from breaking due to expansion or contraction of the metal.

The floor should have a wooden sub-floor under the sheet metal which would be sufficiently strong to carry the weight of the fruit without bending or moving. Any movement is likely to cause binding or twisting of the metal, which would result in gas leakage.

It is good precaution to thoroughly paint all metal surfaces with corrosion-resistant paint. Theoretically, metals in the storage chamber should be more subject to corrosion than in ordinary storage rooms. This assumption is based on the fact that in the controlled atmosphere room there normally exists a condition of high relative humidity along with high carbon dioxide. This combination gives excellent opportunity for the formation of carbonic acid (CO_2 in water). However, observations have not shown that metal surfaces corrode any more in the controlled atmosphere chamber than in other storage rooms.

(2) Gas Tighting Paints.—The following is a description of the method employed in the construction of a controlled atmosphere room and its operation at the Horticultural Division, Central Experimental Farm, Ottawa.

Such commercial preparatory products as "Sealapore," "Nerolac" and "Arcomastic" were used but are not specifically recommended. They proved to be quite satisfactory but there may be other commercial products which would have been equally satisfactory.

The storage room has a rough plaster ceiling and walls and a concrete floor. The first step was to make all these surfaces impervious to the diffusion of carbon dioxide and oxygen. To do this the door and door-frame were removed, all electrical connections and plugs were either removed or submerged below the wall or ceiling surface so that they could be plastered over. The brine coils were disconnected and taken down. The ceiling, walls and floor were all given two thorough coats of Sealapore, one coat of Nerolac, and the ceiling and walls were given an additional coat of aluminum paint. Floor paint (instead of aluminum paint) was applied to the floor to preserve the Nerolac surface. All holes and spaces which were in the ceiling where the brine coils were held in position were filled with vaseline. The bolts were inserted and the space left was filled up with Arcomastic. In addition, rubber washers were used at all joints to render them gas-tight. The brine coils were then put up and reconnected.

Sealing the Door

The door frame was then put together, sealing all joints with vaseline. Any large spaces were covered with paper plastered with vaseline. The door frame was then put in place and any chinks or spaces around the frame were smeared with vaseline and sealed with Arcomastic.

To make the door gas-tight required a special inflated gasket. This gasket was made by vulcanizing together several bicycle inner tubes of the best quality. This gasket was cemented on to a 2-inch by 2-inch frame which was put inside the ordinary door frame extending all the way around and leaving about ½-inch to ¾-inch space between the frame and the inner face of the storage door. The valve stem outlet was carried through the side of the door frame. This was too short to reach the outside so an extension was put on to facilitate inflation of the gasket. The back of the storage door was sheeted with No. 16 gauge galvanized iron, the joints being well soldered. Where the latch bolt projected on the inside, a galvanized iron cap was made, this cap covered the latch bolt with the knob removed and was sealed to the door surface with vaseline. This facilitated easy removal from the inside, ensuring against a person being locked in the storage.

Electrical, Gas Tube Connections, Etc.

For the admission of electrical wiring, etc., conduits were made out of 2-inch black iron piping. These were inserted in the outer wall of the storage so that the inner and outer openings were flush with the wall surface. Rubber stoppers were obtained for either end of the pipe. The wires were then passed through the pipe and later inserted, by means of a slit, into holes bored in the rubber stopper. The rubber stopper on being inserted in the pipe and smeared with vaseline made a gas-tight seal. Any chinks around the conduit wire were filled with Arcomastic. The wires and tubes going through this conduit were as follows:—

1 electric cable for temperature records
1 electric cable for illumination
1 tube for drawing off gas for gas analysis
1 electric cable for thermostat control.

Ventilation Equipment

For ventilation purposes two 3-inch galvanized iron pipes were passed through the same wall as the previously-mentioned conduits—one conduit for an inlet, the other an outlet. The inlet pipe extended to the back end of the storage room. At the outer end this tube was equipped with a snug-fitting metal cap. The outlet tube extended just through the wall of the storage. At the outer end of this was inserted a sliding damper near the wall and beyond this the tube was flared out to encase a small electric fan. When the room requires ventilation the cap on the inlet tube is removed, the outlet damper opened and the fan started. By this means air is drawn from the room and replaced with outside air.

For sub-normal oxygen mixtures a scrubber for removing carbon dioxide without admitting oxygen has to be installed in addition to the above. Details of both types of ventilation are given below.

Gas Analysis

Checking the concentration of carbon dioxide (and oxygen in the case of sub-normal oxygen atmospheres) is essential every twenty-four hours. This procedure only requires a few moments and can be quite easily carried out with the Lunge Nitrometer equipment. A description of this operation is given in Fig. 11 and in the following paragraphs.

By squeezing Bulb B several times the line A from the storage chamber is filled with gas from this chamber. When all contaminating air has been pumped out by this means a sample can be drawn into burette C. In order to do this the burette must be filled with water from levelling bulb D. This is

done by turning stopcock E so that port F is open and raising levelling bulb D until the burette C is completely filled with water, and a slight amount goes into cup H. Then E is turned until port G is open to burette. By lowering the levelling bulb a sample of air is drawn in. By holding the levelling bulb close to the burette a 50 cc sample of gas is measured, making sure that the water level is at the 50 mark, and this in turn is level with the water in the levelling bulb. Stopcock E is then turned so that both ports are closed.

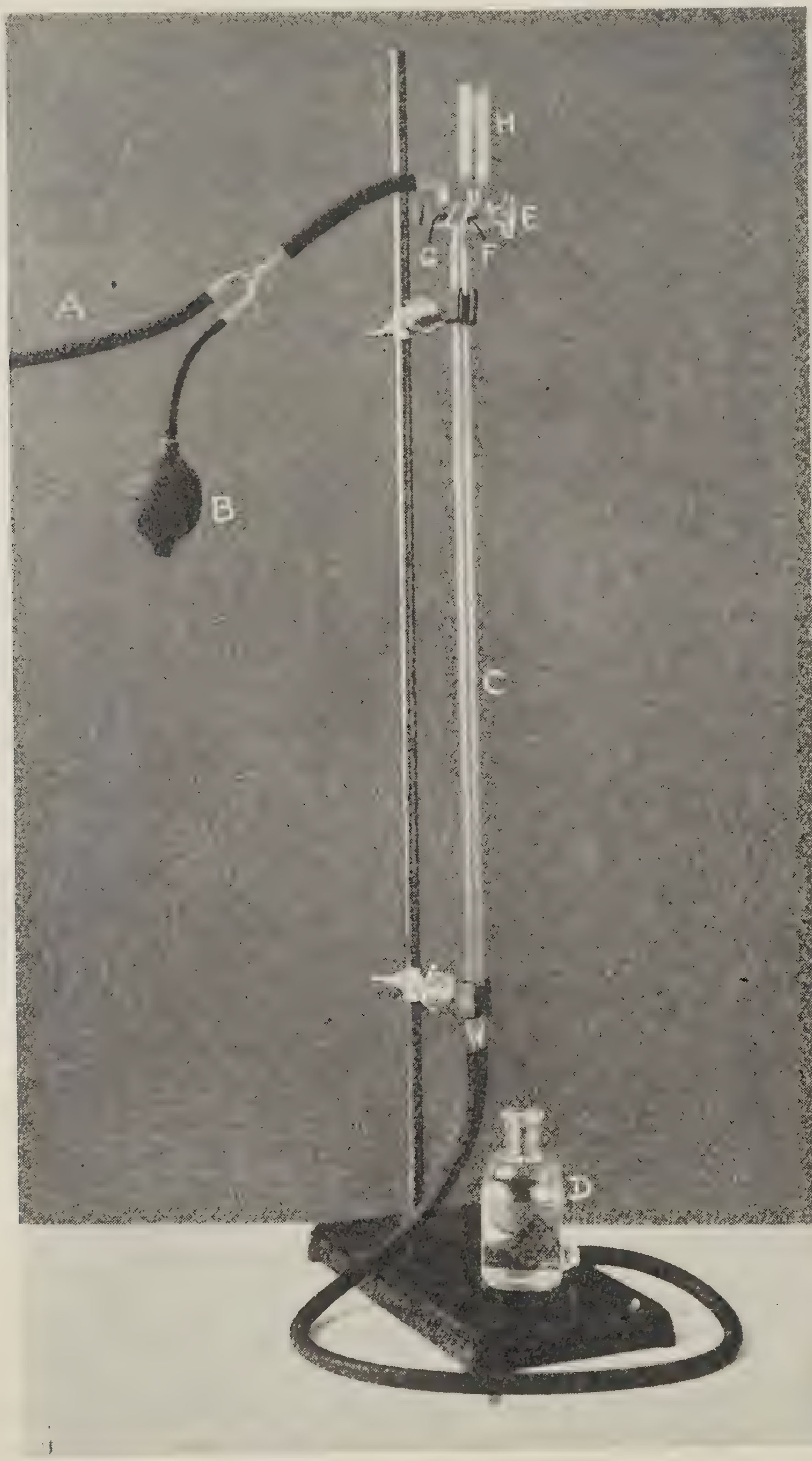

Fig. 11. Lunge nitrometer for determining concentration of CO_2 and O_2. (See text for operation procedure.)

After the sample of gas is in the burette the next step is to absorb the carbon dioxide. This is done by first pouring a 30 per cent potassium hydroxide solution into cup H. (This cup should never be allowed to the

completely emptied during analysis). By turning stopcock E some of the solution is allowed to pass into the burette. It will be noted that the water level in the burette has risen, when the water in the bulb is held at the same level as in the burette. Additional portions of the potassium hydroxide solution are allowed to flow into the burette until the water level ceases to rise (i.e. when readings indicate that no carbon dioxide remains in the gas sample).

In the original volume of the gas sample was 50 cc. and the volume after carbon dioxide removal is 40 cc. it is evident that the carbon dioxide concentration is 20 per cent (50-40=10 cc. of $CO_2=\frac{1}{5}$ original).

After the carbon dioxide has been removed the same procedure is used for oxygen, only instead of using potassium hydroxide, 10 per cent alkaline pyro-gallol solution is used (20 grams pyro-gallol in 200 ml. of 30 per cent potassium hydroxide). This latter solution absorbs both oxygen and carbon dioxide hence it is very important that the carbon dioxide be absorbed first by the potassium hydroxide in order to get true readings.

Another important point is that all readings are made on a volumetric basis hence any change of temperature during analysis will affect the results. A water bath or jacket helps to correct this but will not give indefinite control. For this reason the analysis should be made as quickly as possible. This will come with practice.

Ventilating the Controlled Atmosphere Chamber

(1) Normal Oxygen Mixture.—After the room has been constructed and found sufficiently gas tight it may be loaded and sealed. Routine daily gas analyses are then carried out. When the carbon dioxide has reached or slightly exceeded the desired point some of the air in the room is exchanged for outside air until the concentration of carbon dioxide has been reduced to a safe point. The determining factor, in this regard, is the daily increment of carbon dioxide. This is usually determined by the daily analyses previous to the time when ventilation is required. Let it be assumed that a 7 per cent carbon dioxide mixture is required. The daily readings will start at 0 and gradually increase to 7 per cent. If towards the latter part of these series of analyses the daily increment is 1 per cent, then it would be safe to ventilate to $6\frac{1}{4}$ to $6\frac{1}{2}$ per cent so that the 7 per cent mark would be straddled during the following twenty-four hour period.

One feature which would save time and contribute towards efficient ventilation is to calculate the reduction of carbon dioxide in a given ventilation period. For example, it may be determined that for a ·2 per cent reduction in carbon dioxide a five minute ventilation period is needed. If 1 per cent reduction is required, then a twenty-five minute ventilation period is needed; for ·8 per cent reduction twenty minutes would be needed, etc.

A diagramatic layout of a ventilation system is shown in Fig. 12.

(2) Sub-normal Oxygen Mixture.—The same method of operation is carried out with sub-normal oxygen mixtures as with normal oxygen mixtures except that carbon dioxide is removed by absorption instead of by ventilation as long as the oxygen concentration is adequate. The scrubber shown in Fig. 13 is modelled after the one described by R. M. Smock and A. Van Doren, Cornell University. The principle of this equipment is that air is drawn from the room by a fan. This air passes through a caustic soda spray which absorbs the carbon dioxide. This air is then returned to the sealed storage room. When the daily analysis shows that the oxygen concentration is below the required level, then fresh air is admitted as described for normal oxygen ventilation.

Atmospheric and Temperature Recommendations for Varieties

Controlled atmosphere storage is somewhat further complicated by the fact that different varieties may require different carbon dioxide, oxygen and temperature conditions. Stage of maturity also influences the results obtained in this type of storage in much the same way as in ordinary cold storage. The following results, however, are based on ideal harvesting, packing and general handling methods as outlined elsewhere in this bulletin.

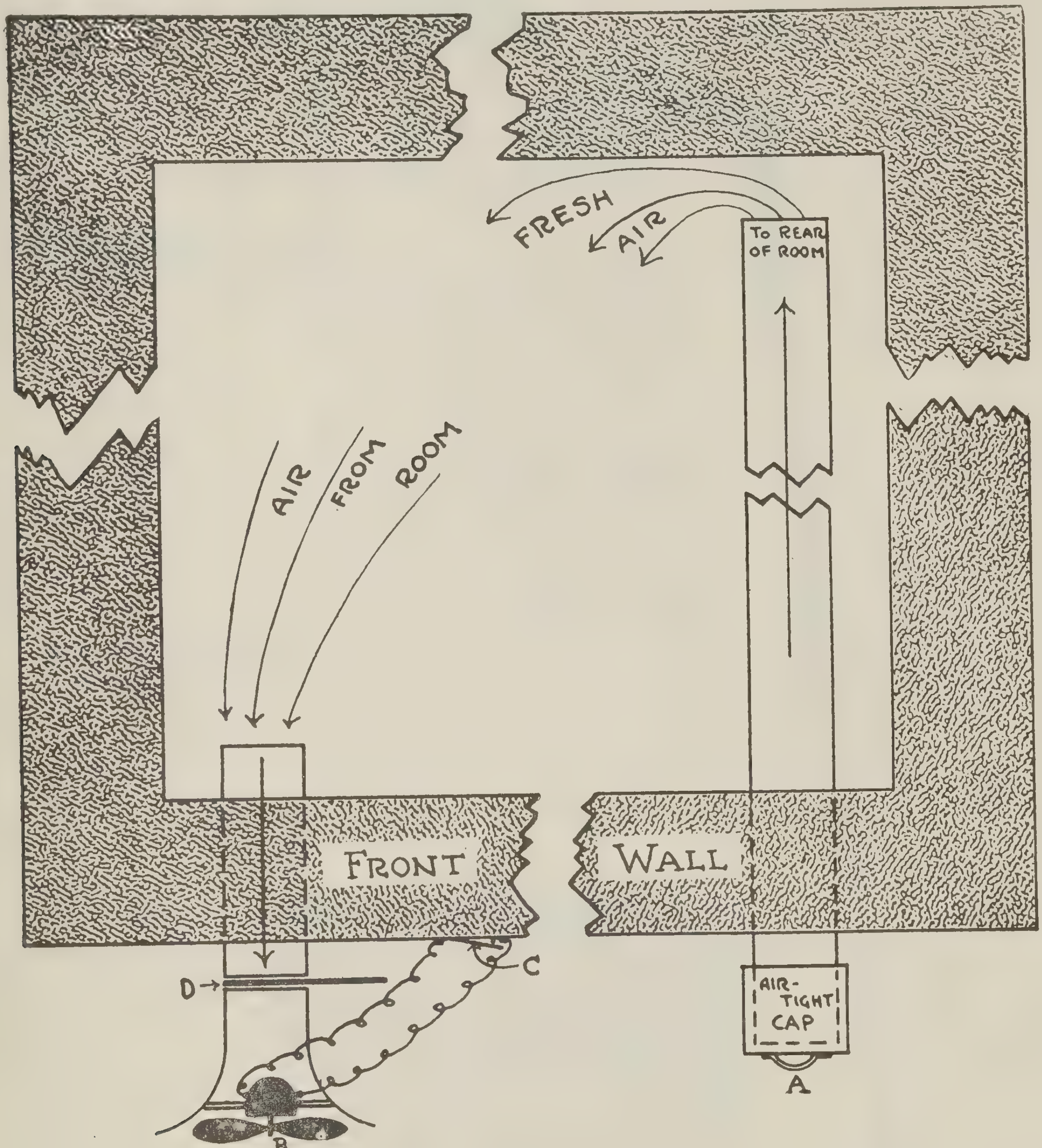

FIG. 12. Diagramatic layout for ventilation system in controlled atmosphere storage room. —A. Inlet cap to be removed for ventilation; B. Fan for pulling air from room; C. Control switch for fan; D. Damper for regulating outward flow of air from room.

It has been claimed by other workers that it is not good practice to store different varieties in the same chamber in spite of the fact that the same atmospheric and temperature conditions are recommended for these varieties. One reason for this is that earlier ripening varieties give off ethylene when ripe thus causing later varieties to mature earlier than they otherwise would. Another reason is that a moderately scald-resistant variety like McIntosh might, under certain circumstances, produce aldehydes, resulting in the pro-

duction of superficial scald in more susceptible varieties. According to preliminary results, however, no deleterious effects were found at Ottawa by storing McIntosh, Fameuse and Golden Russet in the same chamber. As a matter of fact the flavour of the Golden Russet seemed to be improved. None of these varieties is classed as highly susceptible to superficial scald, but there is a considerable variation in their rates of ripening.

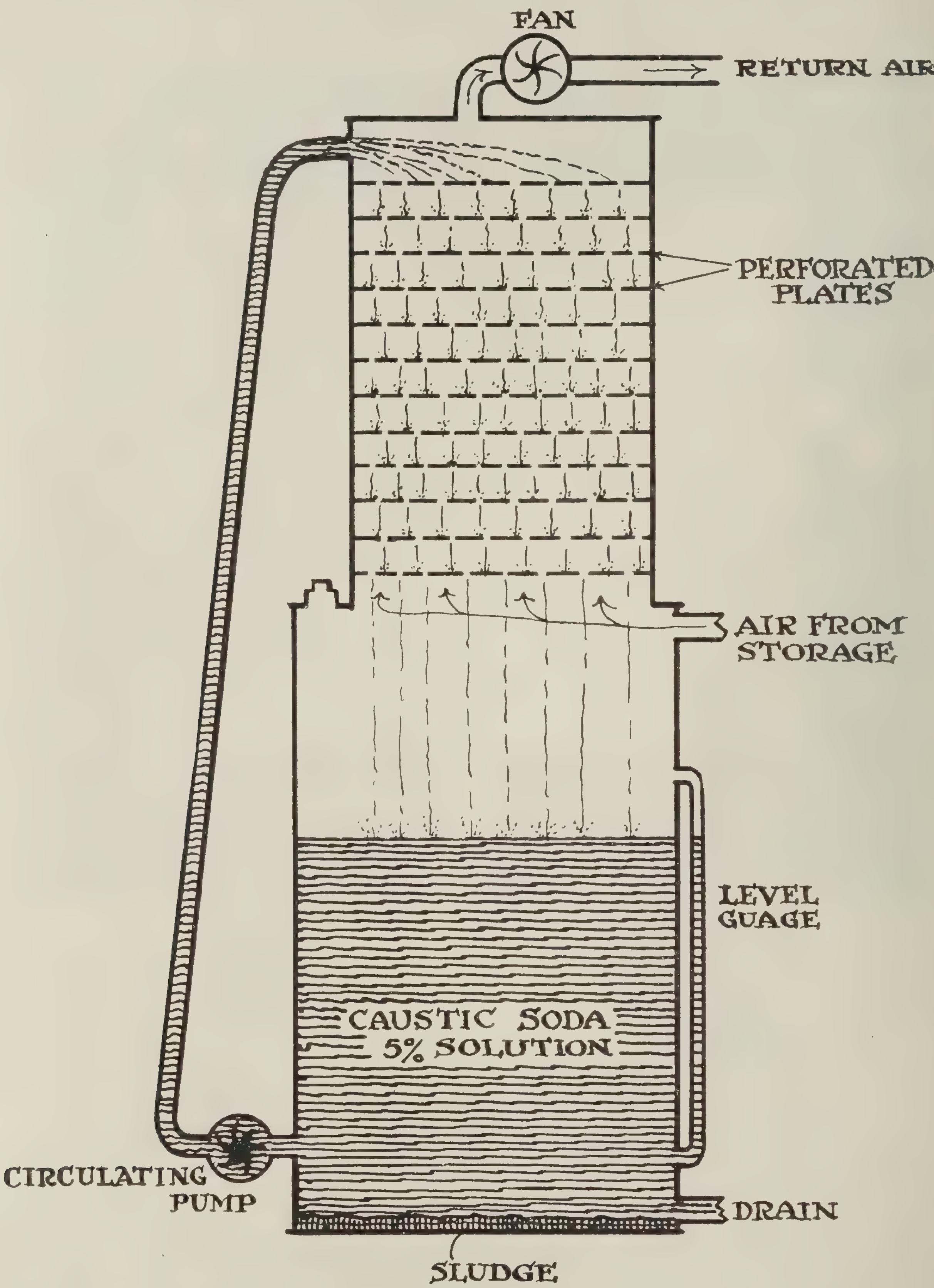

FIG. 13. Longidudinal section of atmospheric washer used for removal of carbon dioxide. (From Smock and Van Doren, Cornell Bull. 762)

Another point which should be given serious consideration in the following information on atmospheric and temperature conditions is that the experiments have progressed much further with varieties like McIntosh, Golden Russet and

Cox Orange than with other varieties. For this reason information of a preliminary nature may be modified by future work on these particular varieties.

McIntosh

This variety does well in either a 7 per cent carbon dioxide and 14 per cent oxygen or a 5 per cent carbon dioxide and 2·5 per cent oxygen at 39°F. Experiments have shown that the latter gas mixture is better than the former, but being a sub-normal oxygen mixture is more expensive from the standpoint of storage construction. In either instance storage life is prolonged and core flush is adequately controlled.

This variety has been tried out on an experimental commercial scale. The consumer's and dealer's reactions have been favourable both as to the high retention of quality and the length of time they hold up after storage.

Golden Russet

A 5 per cent carbon dioxide and 16 per cent oxygen mixture at 32°F. has worked out very satisfactorily for this variety. In a commercial trial retention of moisture and flavour were noted. These apples met with favour when marketed.

Cox Orange Pippin

This variety unfortunately suffers from low-temperature breakdown at 36°F. and lower. If held at safe temperatures (39°F.) their normal storage life cannot be extended beyond the middle of December. Controlled atmosphere storage in preliminary trials has made it possible to carry Cox Orange well beyond the Christmas market. It has been found with this variety that a 5 per cent carbon dioxide and 5 per cent oxygen mixture at 39°F. is best. However, good results were obtained with a 5 per cent carbon dioxide and 16 per cent oxygen mixture at 39°F. If this latter mixture is used it should not be continued after December 1 or when the apples are approaching prime ripeness. At this time normal atmospheric storage at 39°F. should be used, which should be adequate to carry the apples to the end of January. It would appear that this variety becomes quite susceptible to carbon dioxide injury (brownheart) when the full-ripe stage is approached.

Lobo

Preliminary results indicate that 9 per cent carbon dioxide and 12 per cent oxygen at 39°F. is best for this variety. In general, however, this variety cannot be considered as a controlled atmosphere apple. The reason for this is that small differences in maturity cause serious results. The correct stage is when the apples are one half to three quarters blushed, starch test of No. 1 (ground colour and pressure tests are unreliable for this variety). If the maturity is slightly beyond this, breakdown may result.

Gravenstein

Preliminary tests show that a 10 per cent carbon dioxide and 2·5 per cent oxygen mixture at 39°F. is satisfactory for this variety.

Fameuse

A mixture of 5 per cent carbon dioxide and 16 per cent oxygen at 32°F. appear best for this variety. This results in an increased storage life of about 75 per cent but has a tendency to develop a slightly woody texture in the apples

Northern Spy

Maturity is important with this variety. If over-mature, carbon dioxide injury is likely to develop in any of the mixtures tried. However, excellent results were obtained in preliminary trials with a 7 per cent carbon dioxide and

14 per cent oxygen mixture at 32°F. when the apples were harvested in a fairly immature stage; one-third to three-quarters coloured, 1-3 starch test and 17½ pounds pressure test (ground colour appear unreliable for this variety).

Sandow

Preliminary tests show that 9 per cent carbon dioxide and 12 per cent oxygen at 32°F. is satisfactory for this variety. Under these conditions Sandow was held in good storage condition until June.

Delicious

Any amount of carbon dioxide appears to hasten the onset of mealiness, a characteristic termination of storage life of this variety. Reduced oxygen, however, has proved instrumental in prolonging storage life. Either a 2·5 per cent or 5 per cent oxygen mixture in the absence of carbon dioxide has proved satisfactory. The former has resulted in a greater prolongation of storage life accompanied by a slight increase in scald susceptibility. For this reason the 5 per cent oxygen mixture can be regarded as being the more feasible.

Cortland

Maturity is important in this variety. If harvested with ground colour of 5 or more, starch test 5-7 and a pressure of 15 pounds, Cortland does well in a 7 per cent carbon dioxide and 14 per cent oxygen mixture at 39°F. If harvested in a more immature stage Cortland fails to develop quality in controlled atmosphere storage.

Lawfam, King, Jonathan, Rhode Island Greening and Baldwin

Experiments with these varieties so far show no advantage over ordinary storage.

STORAGE NOTES ON VARIETIES

As a general rule 32°F. and 90 per cent relative humidity provide the best storage conditions for apples. As would be expected some varieties keep longer than others under these conditions. The terminations of storage life, however, may be brought by varying causes as between different varieties. With some varieties physiological or fungal disorders may terminate storage life while with others it may be lack of quality or some other cause. There are exceptions also as to storage temperature. Frequently apples suffer from breakdown at 32°F. which can be avoided by storing at higher temperatures. The following represents a summary of findings along these lines for some of the more important apple varieties. (All varieties are subject to fungal rots, particularly when mature, hence this disorder is not mentioned in the summary.)

Baldwin

There is usually little difficulty with this variety at 32°F. and 90 per cent relative humidity. The storage life is usually to March at which time senility sets in. Bitter pit or storage pit frequently occurs on Baldwin. Care in selecting apples from orchards free of bitter pit controls this trouble. If bitter pit is present in the orchard the apples should be left on the tree as long as possible to remove pitted apples before storage.

Ben Davis

Store at 32°F. and 90 per cent relative humidity as for Baldwin. This variety will possibly stand more abuse than any other variety. Can be stored until May.

Cortland

The best storage conditions for this variety are 32°F. and 90 per cent relative humidity. Storage life is terminated about the middle of February by the onset of core flush and by the development of a dry woody texture. It is susceptible to an undetermined disorder which takes the form of hardening or drying out of the tissues in the core area. In samples observed this does not appear to be serious. As with McIntosh maturity of harvest seems to be important with Cortland. If allowed to reach maturity on the tree the storage quality is very much improved.

Cox Orange

This variety is extremely susceptible to breakdown at 32°F. Hence it should not be stored below 36°F. with 90 per cent relative humidity. Controlled atmosphere storage will extend the storage life to the end of January otherwise December is the limit of storage life due to the onset of senility.

Delicious

This is a mild flavoured apple which depends on its high moisture content and crisp texture for appeal. At 32°F. and 90 per cent relative humidity it can be held until March before becoming mealy. Care should be taken with this variety to see that it can stand up a week at least after removal from storage before mealiness sets in.

Fameuse

If stored at 32°F. and 90 per cent relative humidity this variety can be held until December. At this time or later loss of quality is evident followed by the onset of mealy breakdown. Core flush usually develops during November if stored at 39°F. or higher.

Golden Russet

High humidity is required for this variety on account of its high susceptibility to shrivelling, hence 95 per cent relative humidity at 32°F. provides the best storage conditions. If shrivelling is controlled this variety can be marketed until late April. General loss of quality is the limiting factor of storage life. A form of lenticel spotting may cause trouble in storage, but this condition is not common.

Gravenstein

This variety is susceptible to low-temperature breakdown at temperatures below 36°F. particularly if harvested at a late maturity. Hence 36°F. and 90 per cent relative humidity are considered best. This is a short life apple being beyond marketability at the end of November.

Jonathan

When stored at 32°F. and 90 per cent relative humidity Jonathan can be held until the end of January. Jonathan breakdown may develop in several weeks if harvested too mature. Lower temperatures delay the onset of this disorder. When harvested and stored properly general softening, loss of quality and possibility Jonathan spot may determine the end of storage life.

Lawfam

There are no detailed notes on the keeping behaviour of this variety. From general observation, however, it would appear that its storage life is terminated by the middle of February under the best storage conditions which are 32°F. and

90 per cent relative humidity. Storage life is ended at this time by loss of quality. Immature harvest is inclined to induce core flush, but this disorder does not seem to become apparent until the end of February.

Lobo

As with Lawfam recommendations have to be based on general observation. Low-temperature breakdown has been noted on this variety at 32°F. It may be possible that this disorder can be controlled by picking at a certain stage of maturity or by other means. To be safe 39°F. and 90 per cent relative humidity should be used for storage. Under these conditions storage life is limited to the middle of December.

King

The most satisfactory storage conditions for this variety are 36°F. and 90 per cent relative humidity. Core flush and breakdown are inclined to develop at 32°F. Storage life under the best conditions is about the end of January, at which time it becomes over-ripe.

McIntosh

At 32°F. and 90 per cent relative humidity this variety can be stored satisfactorily until the end of January. At this time McIntosh may still look acceptable but the quality will have depreciated to a very low level. High nitrogen or unbalanced feeding, light crop, or immature harvest will cause core flush development when stored at 32°F. Apples harvested under these conditions had better be stored at 39° F. until the ground colour shows a slight tendency to yellow.

Newtown

This variety keeps satisfactorily until May at 32°F. and 90 per cent relative humidity. The important point is to see that Newtowns are harvested at the proper maturity. Early or immature harvest results in core flush, superficial scald and, where susceptible, bitter pit. To control superficial scald oil paper wrapping or shredded oil paper is a good precaution. Apples from light-crop trees and those harvested too early should be stored at higher temperatures and marketed early.

Northern Spy

Because of late maturity and highly aromatic flavours this variety is one of the longest keepers. At 32°F. and 90 per cent relative humidity Northern Spy can be held in good condition until April. On rare occasions it has been known to develop low-temperature breakdown (soft scald type). Sometimes, too, storage pit may be present. This latter disorder may be avoided by delayed harvest, at which time the pit-susceptible apples can be discarded before storage. Many storage operators prefer to delay grading this variety until December on account of susceptibility to bruising when hard and crisp. Storage life normally is terminated by senility and the onset of rots.

Rhode Island Greening

When stored at 32°F. and 90 per cent relative humidity this variety will store to the end of February. Superficial scald is the main storage disorder. Late harvest and oil paper are the most common means of controlling this trouble. Greenings have been known to develop core flush. From results obtained it appears as though this might be a seasonal factor, which is evidently not controlled by temperature or maturity at harvest.

Rome Beauty

This variety if stored at 32°F. and 90 per cent relative humidity can be held to late March or early April. Storage life is usually terminated by loss of quality, softening and general senescense.

Sandow

According to investigations Sandow behaves very much like Northern Spy in storage but may store slightly longer at 32°F. and 90 per cent relative humidity. Under these conditions this variety can be held until late April. Precautions against storage pit should be taken.

Stark

The best storage conditions for this variety are 32°F. and 90 per cent relative humidity. Under these conditions this variety can be held to the end of March. The weakness of Stark is bitter pit hence the general procedure for controlling this disorder should be carried out.

Wagener

When stored at 32°F. and 90 per cent relative humidity this variety can be stored to late March or early April. At this time breakdown is likely to occur. Wagener is also susceptible to core flush at 32°F. but its occurrence seems to be late in the season when senility has been reached. Wagener is also susceptible to superficial scald and for that reason it is a good precaution to use the oil paper treatment.